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Entrainment at a Once-Through Cooling System on Western Lake Erie

Volume I

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16. ABSTRACT

This study assessed entrainment rates and effects for important components of the aquatic community in the once-through cooling system of a steam-electric power plant (the Monroe Power Plant), which can draw up to 85 m^3/second of cooling water from Lake Erie (-80%) and the Raisin River (-20%). Phytoplankton, periphyton, zooplankton, ichthyoplankton, and community metabolism were sampled bimonthly from November 1972 through September 1975. Sampling was conducted at fixed locations in the intake region, discharge canal, thermal plume and the lake-source waters. Concentrations of chloride, dissolved and total solids were used to trace water masses and their associated nutrient and plankton concentrations. At temperatures above 15 C in the discharge canal, photosynthesis was depressed and community respiration was accelerated. Algal abundance increased slightly as green and blue-green algae increased more than other taxa during passage, but algal diversity remained basically unchanged.

Although zooplankton densities declined about 40% in the cooling system, diversity remained unchanged and the impact was masked by mixing in the receiving waters. Larval fish were concentrated near bottom at night and moved up from bottom during the day. Geographical and temporal variation in larval fish distribution were great, but certain species seemed most abundant offshore while others were concentrated near shore.

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ENTRAINMENT AT A ONCE-THROUGH COOLING SYSTEM ON WESTERN LAKE ERIE

Volume I

by

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FOREWORD

Our nation's freshwaters are vital for all animals and plants, yet our diverse uses of water--for recreation, food, energy, transportation, and industry--physically and chemically alter lakes, rivers, and streams. Such alterations threaten terrestrial organisms, as well as those living in water. The Environmental Research Laboratory in Duluth, Minnesota, develops methods, conducts laboratory and field studies, and extrapolates research findings

--to determine how physical and chemical pollution affects aquatic life

--to assess the effects of ecosystems on pollutants

--to predict effects of pollutants on large lakes through use of models

--to measure bioaccumulation of pollutants in aquatic organisms that are consumed by other animals, including man.

This report provides insight into the effects of a once-through cooling system of a fossil fuel plant located on western Lake Erie. Studies were conducted to determine the impact on water chemistry, plankton, periphyton, benthos, and fish larvae.

Donald I. Mount, Ph.D.
Director
Environmental Research Laboratory

ABSTRACT

This study assessed entrainment rates and effects for important components of the aquatic community in the once-through cooling system of a steam-electric power plant (the Monroe Power Plant), which can draw up to 85 m^3/second of cooling water from Lake Erie (~80%) and the Raisin River (~20%). Phytoplankton, periphyton, zooplankton, ichthyoplankton, and community metabolism were sampled bimonthly from November 1972 through September 1975. Sampling was conducted at fixed locations in the intake region, discharge canal, thermal plume and the lake-shore waters. Concentrations of chloride and dissolved and total solids were used to trace water masses and their associated nutrient and plankton concentrations.

River and lake water were well-mixed in the discharge canal following passage through the condenser where the water was heated an average of 6° to 10°C. The thermal plume lost most of its heat to the receiving water rather than to the atmosphere.

The cooling water could rapidly change in chemical and biological character over a few hours because of spatial variation in the source waters. This spatial variation often produced sampling station differences on a particular date which reflected natural, patchy distributions more than cooling system effects. Seasonal and annual means, however, consistently revealed subtle entrainment effects for most of the parameters examined.

Oxygen concentrations in the discharge canal were supersaturated 110 to 120% in winter. No excessive loss of oxygen occurred under the thermal plume. At temperatures above 15°C in the discharge canal, photosynthesis was depressed and community respiration was accelerated. Dissolved organic carbon decreased from decomposition while particulate organic carbon increased enough to offset change in total organic carbon. Algal abundance increased slightly as green and blue-green algae increased more than other taxa during passage, but algal diversity remained basically unchanged. None of the changes in phytoplankton were related to time of day or chlorination schedule. Total non-gaseous nitrogen, inorganic carbon and phosphorus all declined in the plume, apparently improving the water quality from the standpoint of eutrophication. Erosion from the discharge canal, however, contributed excess sediment to the basin.

Although zooplankton densities declined about 40% in the cooling system, diversity remained unchanged and the impact was masked by mixing in the receiving waters. Pilot studies indicated that mortality may have been size related. Leptodora kindtii, along with fish larvae, appeared to be killed by cooling water passage more than smaller plankton. The large zooplankton also were favored as food by juvenile and adult fish in the study area.

Larval fish were at least as effectively sampled with a one meter, 571-μ plankton net as with a Kenco Pump or a high-speed net. Although there was no difference in larval catch in tows of different lengths from one to five minutes, the mesh size was important. Larval fish were concentrated near bottom at night and moved up from bottom during the day. Geographical and temporal variations in larval fish distribution were great, but certain species seemed most abundant offshore while others were concentrated near shore. Because of differential vertical and geographical distribution, some fish larvae seemed more vulnerable to entrainment than others.

Large enough numbers of certain ichthyoplanktonic species and Leptodora kindtii may be entrained to at least slightly influence population abundances of adult organisms in western Lake Erie. Refined assessments are required to ascertain the degree of effect. The regeneration rates of smaller planktonic organisms in the source waters are likely to negate the local impacts of the cooling system on their populations.

This report was submitted in fulfillment of Grant No. R801188 by the Institute of Water Research and the Department of Fisheries and Wildlife at Michigan State University under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period November 1, 1972 to July 1, 1976, and work was completed as of November 30, 1976.

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SECTION 1

INTRODUCTION

Large quantities of planktonic organisms may be drawn into (entrained by) once-through cooling systems at steam-electric power plants. Several decades ago, once-through cooling usually turned out to be the least expensive of a number of possible cooling alternatives. Because the magnitude of the cooling requirement appeared too small to warrent much environmental concern, cost comparisons rarely included assessments of detrimental impact on aquatic communities. This attitude rapidly changed with recognition that the magnitude of the cooling requirement was doubling every decade, an increasing rate that was much faster and in greater quantities than all other combined industrial use. Accordingly, numerous studies of power-plant impact were initiated during the past decade. Only a few of the earlier studies were designed to comprehensively examine impact over several annual cycles (Merriman and Thorpe, 1976). When this study was initiated in 1972, no comprehensive long-term evaluation of cooling-system entrainment had been initiated on the lower Great Lakes. The massive cooling water requirements projected for the Great Lakes region by Dennison and Elder (1970) had signaled potential damage from entrainment effects. This study was conceived to evaluate that potential at the Monroe Power Plant on the west shore of Lake Erie.

The Monroe Power Plant has an exceptionally large once-through cooling system; it pumps up to 85 m^3/sec for cooling purposes. The primary concern of this research was to assess the amount of plankton transported through the cooling system. A secondary objective was to estimate the plant's impact on the structure and function of the entrained planktonic community. The studies results were to be interpreted with regard to the ultimate concern, the impact of the entrainment on the source-water community.

Reviews of the large body of literature on power plant effects (Coutant and Talmage, 1976; Coutant and Pfuderer, 1974) have indicated that entrained organisms may be damaged by plant operation in a number of ways. At the Monroe Power Plant, specific sources of potential damage included (1) alteration of water quality caused by mixing of cooling sources, (2) toxic effects of chlorine, (3) the mechanical damage caused by pump and condenser passage, and (4) thermal "shock" caused by exposure to rapid and prolonged temperature changes. Any of these physical and chemical alterations might have killed at least some organisms or affected their metabolism, growth, and vulnerability to predation or disease.

Other studies have been conducted to specifically assess entrainment impact; some in the field and others in the laboratory. Most of the laboratory studies have inadequately represented power-plant conditions (Shubel, 1974) and many of the field studies have inadequately ascertained variability in the amounts of organisms entrained or the impact of entrainment. To some researchers (Shubel, 1974) the exceptional variability often encountered in field studies requires greater emphasis on laboratory studies; but no laboratory study can estimate the actual quantities of plankton entrained under varying natural conditions. A few studies (Marcy, 1976; Massengill, 1976) have incorporated diurnal, seasonal and annual variation in estimates of entrainment rates or entrainment effects. Most studies have concentrated on some limited aspect of entrainment input such as primary productivity, heterotrophic microorganisms, phytoplankton, zooplankton, or larval fish. Few have integrated their approach to derive a wholistic view that can be contrasted with comparable data from the source-water community. Most comprehensive, completed field studies have been conducted on estuaries or rivers rather than freshwater lakes.

This study used an integrated, community approach which emphasized assessment of both short and long-term variation in order to identify more subtle field impacts than generally have been recognized in the past. To reach that end, studies were simultaneously conducted on phytoplankton, periphyton, zooplankton, ichthyoplankton and community metabolism. These entrainment studies were conducted simultaneously with related studies in the receiving waters described by Cole (1976). Few data are otherwise available for the large, shallow, turbid, warm-water lakes and reservoirs that comprise extensive potential sources of cooling water in the United States. Many of the conclusions presented here may generally apply to those kinds of sites.

SECTION 2

CONCLUSIONS

1. Based on local studies of currents, planktonic organisms from anywhere in the 2500 hectare western basin could be entrained at the Monroe Power Plant, but the most probable regional source is the southwest corner of the basin near the mouth of the Maumee River.

2. Tracers (chloride, dissolved solids and total solids) revealed that chemically discrete water masses often pass through the cooling system over periods of less than one day. Associated plankton populations and nutrient concentrations similarly varied because of spatial variation in the source waters. On any particular sampling date, statistical differences identified among sampling stations in the cooling system reflected patchy distributions more than power plant effects. Seasonal or annual mean concentrations tended to average out the effect of patchiness on the distributions observed in the cooling system.

3. Power plant operation consistently caused minor changes in the mean annual concentration of nutrients and plankton in the receiving waters of Lake Erie. But, in most cases the effects were unrecognizable after the plume water had mixed into the receiving waters.

4. Mean annual gross primary productivity declined about 50% following condenser passage while mean annual community respiration nearly doubled. Gross primary productivity and community respiration recovered as water passed through the cooling system and mixed with the lake waters. Algal concentrations increased slightly, particularly among the green and blue-green algae, as discharge water passed back to the lake.

5. The increased respiration presumably was caused by decomposition of dissolved organics drawn into the cooling system. Particulate organic carbon increased with passage as dissolved organic carbon declined but the total organic carbon exported to the lake remained unchanged. Oxygen depletion in the plume was about the same as in the lake. Winter passage caused an oxygen supersaturation of 100 to 120%.

6. Total non-gaseous nitrogen, inorganic carbon, and phosphorus declined more than expected by simple dilution as water mixed with receiving waters. Considering changes in nutrient concentrations in the water column, the quality of discharge water improved with passage; adding heat may have accelerated the decay of the excessive organic load in the Raisin River. On the other hand, erosion in the discharge canal increased the sediment loading in the discharge water.

7. Mean annual zooplankton densities in the water samples were nearly halved by condenser passage before water passed beyond the upper discharge canal. Pilot studies indicate that mortality was size-related but the numerical decline was not related to the time of day, size or taxonomy of the organism. For most of the smaller species, 50% mortality would have a negligible effect on western Lake Erie because of the relatively large water volume and effective mixing in the basin.

8. Several fish species in the area tend to feed selectively, particularly favoring the large Leptodora kindtii. This species also seemed particulaly susceptible to entrainment effects. The Monroe Power Plant may have acted like a competitor for planktivorous fishes.

9. Open, plankton nets were at least as effective for sampling fish larvae as a Kenco pump or a high-speed net. Length of tow from 1 to 5 minutes did not affect catch rate, but the size of mesh used was crucial. The smallest mesh used, 361-μ, caught more larvae than mesh sizes of 571-μ, 760-μ, or 1000-μ. Oblique tows yielded approximately the same mean yield as stratified tows above the bottom.

10. Larval studies indicated that mortality caused by passage was high, but the larvae of some fish species probably hatched in the discharge canal. Spatial and temporal variability was very great, making it difficult to precisely describe geographical distributions in the basin, particularly for scarce species. Geographical distributions of fish larvae seemed species dependent and some species appeared more abundant offshore than onshore.

11. All larvae appeared to be concentrated very near the bottom during the day and moved up from the bottom at night. Some species stayed close to the bottom more than others, indicating that currents were less likely to carry them long distances than species that moved farther from the bottom. Because of this diurnal cycle, larger numbers of fish larvae are likely to be entrained at night than during the day.

12. Because larvae are closely associated with the bottom during the day and the effectiveness of net sampling near the bottom without using a bottom sled is depth dependent, daytime sampling without a bottom sled is likely to indicate spuriously higher concentrations near shore compared to offshore. Nighttime sampling without a sled is less biased because larvae are less concentrated near the bottom.

13. Species of larval fish and other organisms associated mostly with the river and adjacent marshes seem more vulnerable to entrainment effects than lake populations because most of the river water is used for cooling purposes. Some of these species are relatively important economically and ecologically but are so scarce as larvae in the open lake that it is impossible to effectively judge the impact of the power plant on their populations. These species include centrarchids, ictalurids, esocids and some cyprinids.

14. Relatively small proportions of lake populations appeared to be vulnerable to power plant entrainment; usually less than 0.1 to 1.0% of crudely

estimated basin-wide abundances including yellow perch, white bass, smelt and shiners. Other species may have relatively large proportions of their populations entrained; particularly clupeids and freshwater drum. More information on larval fish distributions, recruitment, and natural mortality is required to refine these preliminary estimates.

SECTION 3

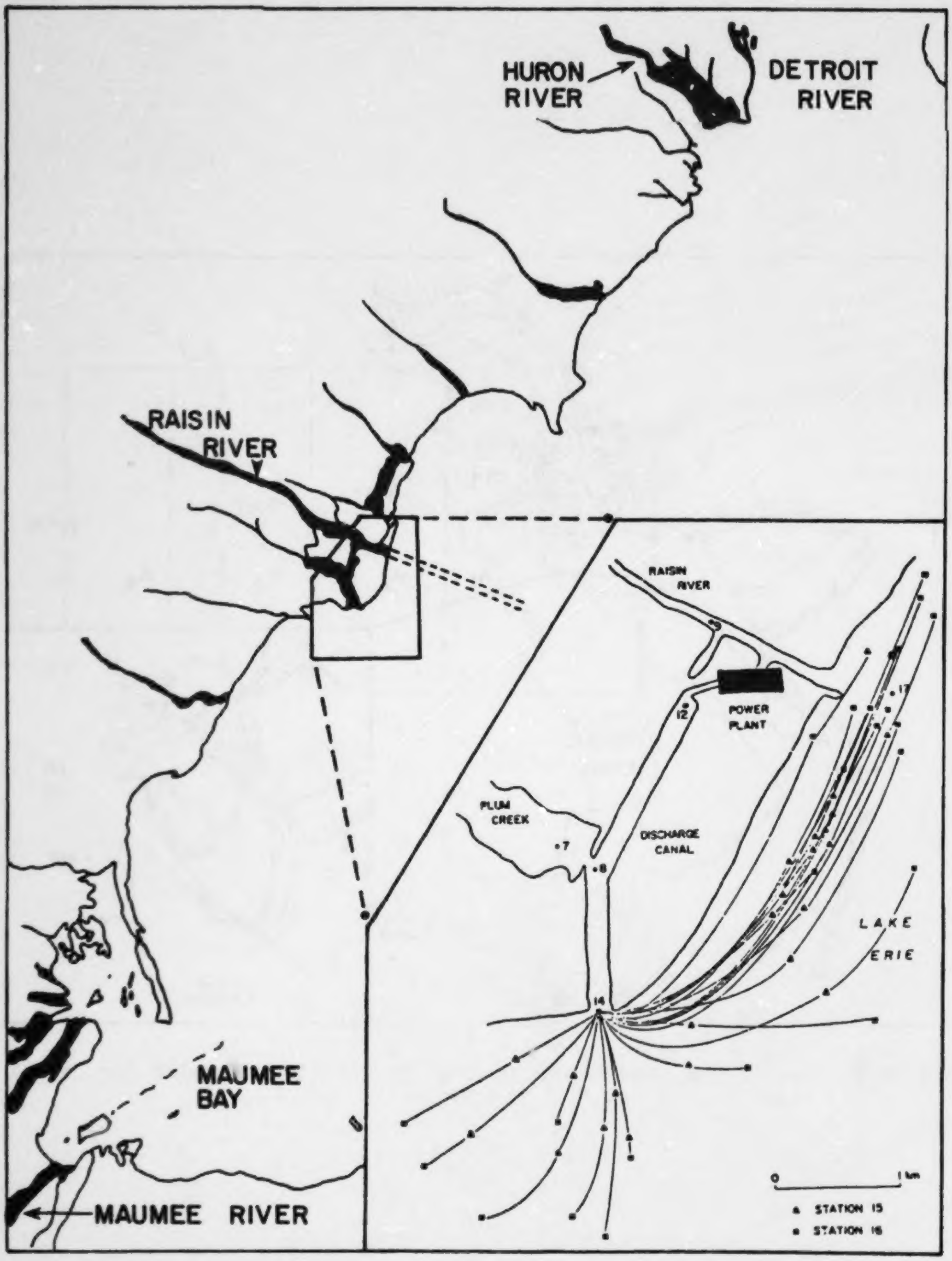
SITE DESCRIPTION

POWER PLANT DESCRIPTION

This study was conducted at the Monroe Power Plant, a fossil-fuel, steam-electric facility operated by the Detroit Edison Company on the western shore of Lake Erie near the Raisin River (Fig. 1 & 2). All four of the plant's generating units were completed by mid-1974 with a net, total capability of 3,150 megawatts. The water demand for once-through cooling depends on power production and ambient water temperature, but the maximum requirement is about 85 m^3 per second. The water is pumped in varying proportions from the Raisin River and Lake Erie. During spring runoff the Raisin River may contribute more than 95 percent of the cooling water while it contributes less than five percent during the low flow of late summer. The biota of the lake and river sources differs, so the species composition in the water passing through the condenser system reflects changes in source-water proportions as well as natural, seasonal fluctuations.

Water enters the cooling system through a 100-m long intake canal that is located about 650-m upstream from the river mouth. Prior to condenser entry, the water passes through a traveling screen with 1-cm, diagonal openings. Water then enters the condenser where water velocities usually exceed 2 m/sec and the temperature rises to about 10°C above ambient at full pumping and power production. But, power generation and pumping rates have varied widely so recorded temperature elevations have ranged from 0 to 17°C. The highest temperature elevations were recorded in winter when cooling water pumping rates per unit of power generation were reduced to supply heated effluent for a recirculation system that is used to control ice accumulation in the intake.

The cooling system has a 27,917 m^2, double-flow Type M, single-pass, divided-surface condenser with 18,154 tubes. Each tube has an effective length of 17.6 m and 2.54-cm outside diameter. The heated condenser water is released into a 350-m long, concrete conduit where water velocities are about 1 m/sec at full operation. The water then passes into a rock-walled, discharge canal which averages 175-m wide, 7-m deep in the upper end, 3-m deep in the lower end and is 2000-m long. At full pumping, the upper discharge canal velocities average about 6 cm/sec and lower canal velocities average about 12 cm/sec. However, the velocity is not uniform because high velocity waters, approaching 1 m/sec, enter the discharge canal from the overflow conduit and form an eddy of slower water on the east side. This adds to the variability of organismic residence times in the discharge canal. Plum Creek drains into the discharge canal but contributes less than one percent of the volume-flow through the lower canal.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RAISIN RIVER
MAUMEE BAY
MAUMEE RIVER
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PLUM CREEK
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DISCHARGE CANAL
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LAKE ERIE
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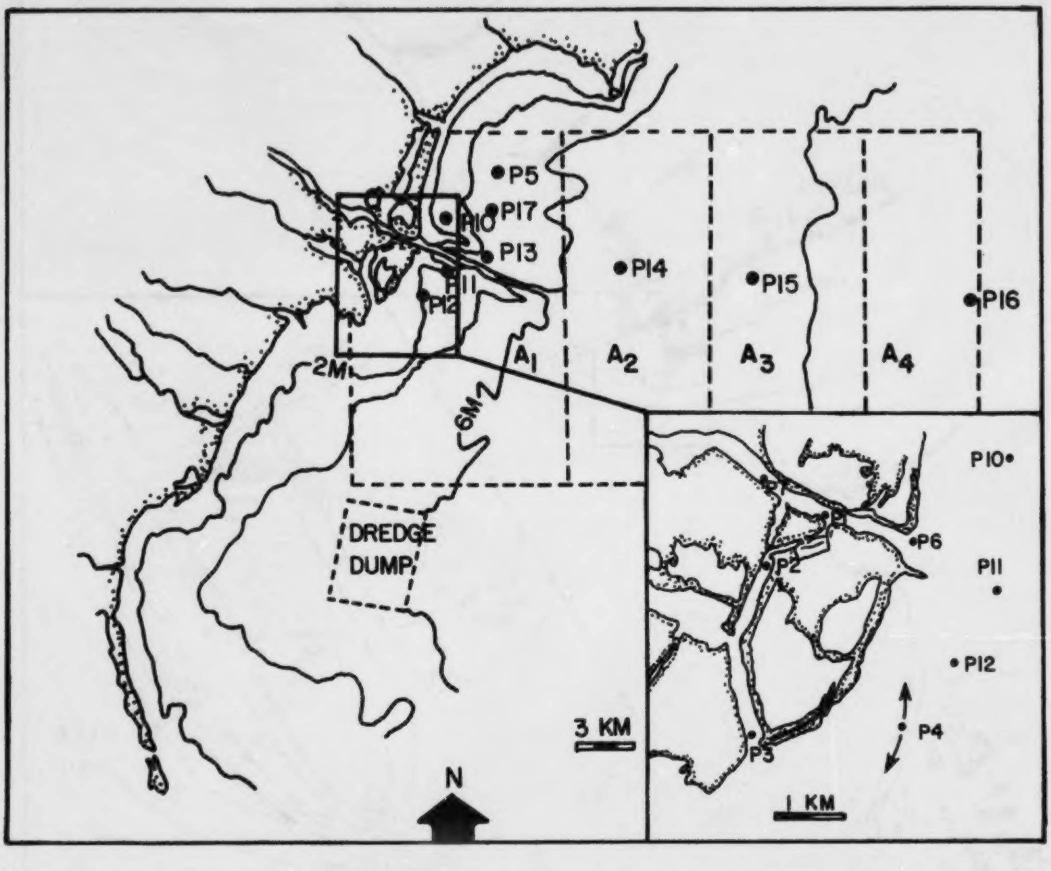
● STATION 16

Figure 1. Map of the study area showing the locations sampled for water chemistry, phytoplankton, zooplankton, community metabolism and periphyton.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1 KM

Figure 2. Map of the study area showing the locations sampled for larval fish.

At full operation, water passage through the cooling system back to Lake Erie averages nearly 4.5 hours. Calculated passage times through the three main parts of the cooling system were seven seconds through the condenser, 20 minutes through the concrete conduit, and four hours through the discharge canal.

The first plant unit started in May, 1971, and the remaining units started at approximately one year intervals thereafter until completion in May, 1974. Preliminary operations were erratic, but stabilized as more units contributed power; 94 percent of all plant shutdowns to date occurred in 1971 and 1972 (The Detroit Edison Company, 1976).

After leaving the discharge canal, the heated effluent formed a plume which extended up to 6 km from the mouth of the canal. The largest plume measured by The Detroit Edison Company (1976) encompassed about 860 ha to the 1.7°C (3°F) isotherm. The plume position and size depended on the pumping rate, power generation rate and the direction and velocity of the wind. Heat dissipation from the plume occurred within one to two days.

Chlorine was added to the cooling water at the intake to control growths in the condenser; two times per day during summer and once per day during winter. During the warm months (April-October), chlorine was added at one hour intervals for four hours starting at 0700 hours and then again for four hours at 2030 hours. In winter, chlorine was injected for 0.5 hour periods at 0700, 0900, 1100, and 1300 hours. The highest concentration of chlorine measured in the upper discharge canal by the Company was 0.29 mg/liter (The Detroit Edison Company, 1976).

THE COOLING WATER SOURCES

The western basin of Lake Erie is a shallow ($\bar{d}$ = 7.3 m), highly turbid area that is partially separated from the rest of Lake Erie by the Bass Islands and Point Pelee. Beeton (1961) attributed the high turbidity to wind-generated resuspension of sediments, river discharges, and plankton. Photometric measurements made during this study indicated that only 0.1 percent of the total mean surface light penetrated to the 5-m depth during spring and summer. Wind-generated mixing usually maintains vertical homeothermy in the basin but calms occasionally allow temporary stratification for a few consecutive days (Carr _et al_., 1965).

The surface area of the basin is 3,276 km^2 (Carr _et al_., 1965) and the shoreline is characterized by natural and artificial islands, peninsulas, spits, and flooded river mouths. The spatial diversity along the shores provides numerous types of fish-spawning habitat including marshes, rocky reefs, and sand and gravel bars. Most of the bottom sediment near shore is composed of coarse, medium, and fine sand which grades into silt and clay in the deeper waters off shore (Kelly and Cole, 1976).

The Detroit River annually contributes about 95 percent of the flow to the western basin of Lake Erie while the Maumee River, the second largest tributary, contributes 2.5 percent. The Raisin River contributes less than 0.3 percent (Ecker and Cole, 1976). The locations of these rivers are shown in Figures 1 and 2. Significant numbers of larval fish may enter the study area from each of these rivers. The combination of tributaries and prevailing southwesterly winds generally causes the water in the southwestern corner of the basin to circulate in a clockwise eddy (Hartley _et al_., 1966). But, pronounced day to day variations can occur because of changing winds and tributary discharge. Water from the Detroit River predominates off shore while water from the Maumee and Raisin Rivers dominate the west shore south of Stony Point. Mean resultant water velocities in the lake are 1.6 to 2.0 km/day; but during storms, plankton from either the Detroit or Maumee Rivers could reach the study area within a day and plankton from the island region of the basin could reach the power plant in two days. Wind velocities of 51.5 km/hour or more occur an average of 23 days/year.

Until recently, the lower Raisin River was highly polluted with municipal and industrial wastes, particularly biodegradable organics. Anoxia was once common during summer, but improvements in waste treatment have partially mitigated harmful impacts.

SECTION 4

MATERIALS AND METHODS

WATER MOVEMENT

Current velocities were estimated with drogues, a Gurley Current Meter, a film recording current meter (General Oceanics) and calculations based on cooling system morphometry and pumping rates. The Gurley Current Meter was used to sample 23 to 26 points along a cross sectional profile of the concrete conduit just upstream from where it entered the discharge canal. Drogues were constructed from two masonite panels (0.6 x 1.2 m) set perpendicular to each other and weighed to equilibrium with the water. These were attached to a 38 cm x 2.5 cm styrofoam float. The drogues were followed for one to several hours and the distances recorded. The film recording current meter yielded data from near bottom in the lower discharge canal for 14 days in 1973 and at P10 in the lake for 20 days in 1975. It also yielded data from 2.5 m at P10 for nine days in 1975. Drogues were set at the surface and 1-m and 3-m below the surface at station P10. For current measurements within the cooling system drogues were set at 1 to 5-m depths in sets of five replicates. Pumping rates were obtained from records kept by the Detroit Edison Company and calculations based on chloride concentrations.

CHEMISTRY, PLANKTON AND PERIPHYTON

Chemistry

The water chemistry, phytoplankton, zooplankton and primary productivity all were sampled at the same stations (Fig. 1) and on the same schedule (Table 1).

The sampling for plankton, primary productivity and water chemistry was conducted at seven stations in the cooling system. The river and lake sourcewaters were sampled at stations 9 and 17. The water at those two locations could be representatively assessed with relatively few samples in contrast to the water in the short (100 m) intake canal which was usually incompletely mixed with highly variable proportions and distributions of lake and river waters. Therefore, intake station 18 was calculated by proportioning flows from the river and lake once the proportions of lake and river water had been calculated from data gathered on chlorides, total solids, dissolved solids, plant pumping rates and U.S.G.S. measures of river discharge. Virtually all river water is drawn into the cooling system, and the balance is made up by lake water. U.S.G.S. flow data came from 10-km upstream, and therefore,

TABLE 1. SUMMARY OF SAMPLES COLLECTED AND PROCESSED FOR CHEMISTRY, PRIMARY PRODUCERS AND ZOOPLANKTON, 1972-1975

Date (Hours)	Temperature and Oxygen	Chloride and Total Solids	Nutrient Chemistry	Phytoplankton	Gross Productivity	Zooplankton	Periphyton
1972-73	S* R# T†	S R T	S R T	S R T	S R T	S R T	S R T
Nov. 9 (5-10)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	
Nov. 9 (21-2)	7 5 35	7 5 35		7 5 35	5 3 15	7 5 35	
Nov. 10 (12-17)	7 5 35	7 5 35	7 5 35	7 5 35	6 3 18	7 5 35	Ice Problems
Jan. 18 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	
Jan. 25 (12-17)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	
Jan. 26 (5-10)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	
Mar. 30 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	3 3 9	7 5 35	May 5-May 30
Apr. 5 (12-17)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	7 2 14
Apr. 6 (5-10)	7 5 35	7 5 35		7 5 35	6 3 18	7 5 35	
June 11 (21-2)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	July 10-July 31
June 12 (12-17)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	7 2 14
June 13 (5-10)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	
Aug. 8 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	
Aug. 9 (12-17)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	
Aug. 10 (5-10)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	
Sept. 28 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	
Sept. 29 (12-17)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	
Oct. 1 (5-10)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	

*S = Number of stations
#R = Replicates per station
†T = Total samples

(continued)

TABLE 1 (continued).

Date (Hours)	Temperature and Oxygen	Chloride and Total Solids	Nutrient Chemistry	Phytoplankton	Gross Productivity	Zooplankton	Periphyton
	S* R# T†	S R T	S R T	S R T	S R T	S R T	S R T
1973-74							
Dec. 12 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	4 5 20	
Dec. 13 (12-17)	7 5 35	7 5 35	7 5 35	4 5 20	7 3 21	4 5 20	
Dec. 14 (5-10)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	7 5 35	
Jan. 31 (21-2)	7 5 35	7 5 35	7 5 35	5 5 25	7 3 21	4 5 20	Feb. 14-Mar. 15
Feb. 1 (12-17)	7 5 35	7 5 35		4 5 20	7 3 21	4 5 20	7 2 14
Feb. 2 (5-10)	7 5 35	7 5 35		5 5 25	7 3 21	5 5 25	
April 10 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	4 5 20	
April 11 (12-17)	7 5 35	7 5 35	7 5 35	4 5 20	7 3 21	4 5 20	
April 12 (5-10)	7 5 35	7 5 35		7 5 35	7 3 21	7 5 35	
June 11 (21-2)		7 3 21	4 5 20	7 5 35	7 5 35		
June 12 (12-17)	4 5 20	7 3 21	4 5 20	7 5 35			July 10-July 31
June 13 (5-10)	4 5 20	7 3 21		7 5 35			
Aug. 14 (21-2)	7 5 35	7 5 35	7 5 35	7 5 35	7 3 21	4 5 20	
Aug. 15 (12-17)	7 5 35	7 5 35		4 5 20	7 3 21	4 5 20	
Aug. 16 (5-10)	7 5 35	7 5 35		7 5 35	7 3 21	4 5 20	
Oct. 19 (5-10)	7 5 35	7 5 35		7 5 35	7 3 21		
Oct. 20 (21-2)	7 5 35	7 5 35	7 5 35	4 5 20	7 3 21	4 5 20	
Oct. 21 (12-17)	7 5 35	7 5 35		4 5 20	7 3 21	4 5 20	

*S = Number of stations
#R = Replicates per station
†T = Total samples

(continued)

TABLE 1 (continued).

Date (Hours)	Temperature and Oxygen			Chloride and Total Solids			Nutrient Chemistry			Phytoplankton			Gross Productivity			Zooplankton			Periphyton		
1974-75	S*	R#	T†	S	R	T	S	R	T	S	R	T	S	R	T	S	R	T	S	R	T
Jan. 24 (21-2)	7	5	35	7	5	35	7	5	35				7	3	21	4	5	20			
Jan. 25 (5-10)	7	5	35	7	5	35							7	3	21						
Jan. 25 (12-17)	7	5	35	7	5	35				4	5	20	7	3	21	4	5	20			
March 15 (12-17)	7	5	35	7	5	35				4	5	20	7	3	21	4	5	20			
March 16 (21-2)	7	5	35	7	5	35	7	5	35				7	3	21	4	5	20			
March 17 (5-10)	7	5	35	7	5	35							7	3	21						
May 16 (21-2)	7	5	35	7	5	35	7	5	35				7	3	21	4	5	20			
May 17 (12-17)	7	5	35	7	5	35				4	5	20	7	3	21	4	5	20			
May 18 (5-10)	7	5	35	7	5	35							7	3	21						
July 27 (21-2)	7	5	35	7	5	35	7	5	35				7	3	21	4	5	20			
July 28 (12-17)	7	5	35	7	5	35				4	5	20	7	3	21	4	5	20			
July 29 (5-10)	7	5	35	7	5	35							7	3	21						
Sept. 15 (21-2)	7	5	35	7	5	35	7	5	35				7	3	21	4	5	20			
Sept. 16 (12-17)	7	5	35	7	5	35				4	5	20	7	3	21	4	5	20			
Sept. 17 (5-10)	7	5	35	7	5	35							7	3	21						

*S = Number of stations
#R = Replicates per station
†T = Total samples

underestimated river flow at the power plant. A partial correction of 1.5 m^3/sec was made to account for additions from the City of Monroe, Michigan.

The discharge canal was sampled at the upstream end (station 12), the middle (station 8), and the downstream end (station 14). The thermal plume was sampled at station 15, a point located along the central axis where the temperature was about one-half the difference between the lake temperature and the temperature in the lower discharge canal. For example, when Lake Erie was 10°C and the lower discharge canal was 18°C, station 14 was about 14°C. Station 16 was located along the central axis near the plume edge at a temperature about 1 to 2°C above ambient.

Chemical distributions were sampled every 8 to 10 weeks. Each station was sampled with a 4.1 or 8.1-liter Van Dorn water bottle. Five replicates were obtained from each station at randomly located depths except at stations 14 to 16. Because these latter stations were shallow, station 14 (3-m deep) was sampled near the surface and just above the bottom, while the two plume stations (1 to 2 m deep) were sampled only near the surface.

Water temperature and oxygen concentration were measured in duplicate at each of the seven stations at 1-m intervals from the surface to the bottom. Those samples, as well as samples used to assess the concentrations of chloride and total solids, were taken at three time periods on each sampling trip. The time periods were in the morning (0800 to 1200), afternoon (1300 to 1800), and evening (0900 to 0100). This sampling effort was the same from November, 1972, to September, 1973. The remaining chemical parameters were measured only for one of the three sampling times on each sampling trip (Table 1); but not necessarily the same time period on all trips. These chemical parameters included suspended solids, dissolved solids, total phosphorus, nitrate-nitrogen, ammonia-nitrogen, total organic carbon, and dissolved organic carbon (<0.45μ). Particulate phosphorus and organic carbon were calculated by difference between total and dissolved concentrations. Organic nitrogen was calculated by the difference between Kjeldahl-nitrogen and ammonia-nitrogen. Previous work (Cole, 1972) established that nitrite concentrations were negligible in the study area so total inorganic nitrogen and total non-gaseous nitrogen were calculated only from nitrate-notrógen, ammonia-nitrogen, and organic-nitrogen.

Temperature and oxygen were measured with a YSI oxygen meter that was regularly standardized against Winkler titrations. Oxygen measurements were within 0.5 mg/liter of the Winkler determinations. Percent saturation of oxygen was calculated from data presented in A.P.H.A. (1971). Chemistry was measured mostly as outlined in EPA (1971). Water samples for everything but chloride were preserved in the field with Hg_2Cl_2, then analyzed as described by EPA (1971). Chloride samples were not preserved.

The total suspended solids (seston) were defined as the dry weight gain of a millipore filter (0.45-μ) from 100-ml of water passed through the filter. The filters were dried in a dessicator, weighed and then dried to constant weight. Two sample blanks were flushed with distilled water and handled similarly in every respect. Weight changes in the blanks were assumed to be caused by moisture. The estimates of suspended solids were corrected for the measured moisture accumulation that could not be removed from the filter by dessication. To determine total solids, unfiltered samples were evaporated to constant, dry weight. Dissolved solids were calculated as the difference between total solids and suspended solids.

Phosphorus concentrations were determined by a modification of a technique described by Wadelin and Mellon (1953). Both total and filtered (0.45-μ), 50-ml aliquots were hydrolized to determine total and "dissolved" phosphorus, respectively. About 10-ml of double-distilled water were added to the boiling flasks, then the contents were neutralized with phenothalien, 0.02 $N_2H_2SO_4$ and 0.2 NaOH. Then the samples were transferred to 500-ml, pear-shaped, separatory funnels. Each flask was rinsed twice with 10 ml of double-distilled water and each rinse was added to the funnel with 4 ml of concentrated hydrochloric acid, 15 ml of 1-buterol and 15 ml of chloroform-buterol mixture. The funnel was then stoppered and shaken for 5 minutes. After complete separation, the lower layer was drained away. Exactly 10 ml of chloroform-buterol were added with 3 ml of a 10 percent, ammonium molybdate solution. The funnel was then shaken for 4 minutes and, after separation, the absorbance of the lower layer was determined at 310 mμ.

Nitrate-nitrogen was determined with the modified Brucine method described by Jenkins and Medsker (1964). Ammonia-nitrogen and Kjeldahl nitrogen were determined as described by EPA (1971) but the 50-ml sample was distilled following nesslerization.

Carbon concentrations were determined on a Beckman single-channel carbon analyzer as described by the EPA (1971). Total organic carbon was determined after adding HCl to a pH <1. Dissolved organic carbon was analyzed by passing a sample through a cleaned (flushed with 250-ml of distilled water), 0.45-μ Millipore filter, treating with HCl until the pH was ≤ and then sweeping with nitrogen.

Phytoplankton

Phytoplankton samples were drawn from the same Van Dorn water collections used for chloride and total solids (Table 1). During the first year of the study; to September, 1973, emphasis was placed on the short-term variation associated with different times of the day (morning, afternoon and evening) and different locations in the cooling system. All phytoplankton were identified to the most specific taxa possible only in the afternoon samples. Morning and evening samples were identified to class.

After September, 1973, in the last two years of the study, the emphasis was placed on long-term annual comparisons of entrainment rates rather than short-term variations. Plankton were sampled only at stations 17, 9, 12 and 14 (5 replicates each as in the first year) in the afternoon. All phytoplankton were identified to genus, except at station 12, where they were still identified to species whenever possible.

Subsamples of 480 ml were drawn off and preserved with 20 ml of 37% formaldehyde solution for all phytoplankton collections. Algae were enumerated with the membrane-filter (0.45-μ) technique described by McNabb (1960) and adapted by APHA (1971). Algal counts were based on the natural living unit, be it a cell, colony, or filament. The conversion from a taxon's frequency in 30 microscope fields to their sample density was determined using the following equation:

$$\text{numbers/ml} = \frac{d}{(\text{quadrant area in } \mu m^2) \times (\text{ml filtered})}$$

where d is the theoretical density corresponding to a given frequency.

The diatoms collected on the filter could be reliably identified only to the centric or pennate taxonomic level. Species identifications were made from permanent mounts prepared according to Weber (1970) from combined concentrates of replicates from one station. The proportions of species found in these preparations were then used to calculate the abundance of each species collected on the filter.

The phytoplankton identifications were derived from keys and descriptions which included Hustedt (1930), Taft (1945), Taft and Taft (1971) and Weber (1970). The coccoid blue-green algae were classified according to the revisions by Drouet and Daily (1956). Some questionable forms were referred to Dr. D.C. Jackson and Dr. F. Begres of Eastern Michigan University at Ypsilanti, Michigan.

The volume of a taxon in a sample was calculated by multiplying the density by the estimated, mean specimen volume. The mean specimen volume was determined from modified, geometric formulae applied to sizes of the counted specimens. The mean volumes were averaged for all stations sampled on one date. If fewer than 10 specimens were observed on a single collecting date, a mean annual, specimen volume was used for all dates. The mean specimen volumes of phytoplankton classes were calculated as the sum of all class volumes. The biomass (carbon content) was derived from volume estimates using formulae calculated by Strathmann (1967).

Diversity indices were computed for algae collected at each station using Shannon's index as described in Pielou (1969, pg. 231-235). Evenness, or equitability, was computed as $E = \bar{H}/\log_{10} s$ where $\bar{H}$ is the diversity index and s is the number of different taxa present.

Tests of differences among stations were conducted using analysis of variance after all data were transformed logarithmically. When significant differences appeared, Tukey's multiple comparison test was applied at $\alpha = 0.05$.

Periphyton

The attached communities were sampled during each of the four seasons in 1973 and 1974 at the same stations sampled for chemistry and plankton (Table 1). Weather sometimes disrupted sampling at stations 15 and 16 in the lake. Rates of periphytic accumulation were assessed with replicate pairs of styrofoam blocks (2.5 cm x 5.1 cm x 7.5 cm) which were collected every 5 to 7 days over a 3 to 4 week period. The slides were suspended about 0.5 m below the surface. The retrieved substrates were frozen until they were processed. The styrofoam outer wall, along with the attached growth, was shaved into xylene which dissolved the styrofoam. Then the attached growth was filtered from the solution with 0.45-μ millipore filters.

Zooplankton

The zooplankton were sampled from the same 5 replicates per station used for chloride and total solids. As with phytoplankton, the first year's (November, 1972, to September, 1973) sampling emphasis was placed on short-term variation associated with different times of the day and different locations in the cooling system. All zooplankton were identified to the most specific taxa in all replicates. After September, 1973, in the last two years of the study, the emphasis was placed on long-term, annual comparisons of entrainment rates rather than short-term variation. Zooplankton were then sampled with 4 replicates at a station only in the afternoon and evening at stations 7, 9, 12 and 8.

The zooplankton were sampled with an 8.1 liter, Van Dorn water bottle. The contents were concentrated in the field by pouring them through a #25 Wisconsin plankton bucket. They were preserved with 5 percent formalin. Samples were diluted to known concentrations before a 1-ml subsample was counted in a Sedgwick-Rafter cell. The animals were counted, identified to species when possible, and measured using a whipple micrometer.

Zooplankton volumes were estimated by using linear measurements of the length and maximum width to calculate the volume of common geometric figures which best approximated the shape of the animal. Dry weights were calculated from the volumes by assuming that the organisms were 90% water and their specific gravity was 1.0 (Cummins and Wuycheck, 1971). Like phytoplankton, the zooplanktonic diversity was determined using the diversity index described by Pielou (1969).

Spatial and temporal differences were tested with analysis of variance after the data were corrected for heterogeneity of variance. Tukey's test of multiple comparisons was applied when significant ($\alpha < 0.05$) differences existed. Linear regression analyses were also used to assess the relation between depth and the distribution of the major taxa.

Community Metabolism

Gross primary productivity and community respiration were measured at the same 7 stations in the cooling system by the change in oxygen technique described in APHA (1971). Three, 300-ml light bottles and three, 300-ml dark bottles were set near the surface (0.5-m deep in 1972-73 and 0.2-m deep in 1973-75) at all stations. Bottles were suspended in the morning, afternoon and evening on all trips made from 1972 to 1975. Water was collected at the surface with an 8.1-liter Van Dorn bottle from which all station test-bottles were filled. The bottles were suspended at 0800 to 1230 hours, 1200 to 1800 hours and 2100 to 0100 hours over the study period. Incubations on a particular date never were less than 2 hours or more than 4.5 hours.

FISH AND MIDGES

Midges

Midges, drifting through the cooling system as larvae or pupae, were collected in the 1973 samples that were intended for pilot studies of larval fish distributions. They were captured at stations P1 to P5 (Fig. 2) using a 1-m plankton net with 571-μ mesh openings. Each station was sampled with 6 tows; each 5-min long (about 150m^3 of water). Two tows each were made at the bottom, mid-depth and the surface wherever there was enough depth to differentiate. Sampling was conducted every 1 to 2 weeks during May and June. All samples were preserved in 5 percent formalin. No attempt was made to identify the midge larvae and pupae.

Non-larval Fish

Food habits of non-larval fish found in the cooling system were investigated during the study period. The zooplanktivorous food habits of four fish species common in the study area were examined in conjunction with studies conducted on zooplankton entrainment. These data are presented in a report by Kenaga and Cole (1975) which is included in Appendix (A).

Larval Fish

Larval fish were first sampled in a pilot study conducted during 1973 (Table 2). Sampling took place at Stations P1 through P5. In 1974 and 1975, studies of larval fish entrainment were expanded and modified so that samples were taken at stations P2, P3, P6, P7, P10, P11 and P12. The changes were made to improve estimates of larval fish entrainment into the cooling system. Sampling in the plume at Station P1 was not satisfactory because the area to be sampled was often too shallow. Instead, sampling was conducted at three permanent stations in deeper water which were usually down-current (north) from the thermal plume. These three stations served to estimate the variability of larval populations in the lake near shore where there was a high probability of eventual entrainment into the cooling system.

In May and June, 1975, additional studies were conducted on larval fish distribution in the lake, larval fish mortality in the cooling system, and the comparability of different capture techniques for larval fish in the lake. Four stations, P13 through P16, were sampled along a transect which extended 16-km toward the center of the western basin. The purpose of this sampling effort was to tentatively assess how fish larvae were distributed in relation to shore. At another station, P17, daytime comparisons were made of results from different sampling techniques including a Kenco pump, high-speed plankton sampler, and 1-m plankton nets of several different mesh sizes. Station P17 was also the site used to compare plankton-net tow lengths and larval depth distributions during the day and night.

The Kenco pump, high-speed plankton sampler and 1-m plankton net were used on the same days for comparison. The Kenco pump was submersible with a realized pumping capacity of 6.9 liters per second. It was submersed at the bow of an anchored boat to a depth of 0.25 meters and run for one hour. Pump effluent

TABLE 2. LARVAL FISH SAMPLING SCHEDULE

Dates	STATION													
	P1	P2	P3	P4	P5	P6	P7	P10	P11	P12	P13	P14	P15	P16	P17
Cooling system distributions															
1973*															
05/11	X	X	X	X	X										
05/17	X	X	X	X	X										
06/01	X	X	X	X	X										
06/08	X	X	X	X	X										
06/15	X	X	X	X	X										
1974†															
05/10		X	X												
05/29-30		X	X			X	X	X	X	X					
06/11		X	X			X	X	X	X	X					
06/21		X	X			X	X	X	X	X					
07/01		X	X			X	X	X	X	X					
07/15		X	X			X	X	X	X	X					
07/26		X	X			X	X	X	X	X					
						X	X	X	X	X					
1975†															
05/12-13		X	X												
06/02		X	X			X	X	X	X	X					
06/25		X	X			X	X	X	X	X					
07/09		X	X			X	X	X	X	X					
07/31		X	X			X	X	X	X	X					
						X	X	X	X	X					

(continued)

TABLE 2 (continued)

Dates	P1	P2	P3	P4	P5	P6	STATION P7	P10	P11	P12	P13	P14	P15	P16	P17
Transect‡															
1975															
05/22											X	X	X	X	
05/23											X	X	X	X	
06/09											X	X	X	X	
06/16											X	X	X	X	
06/19											X	X	X	X	
07/02											X	X	X	X	
07/22											X	X	X	X	
Gear Comparison and Day-Night#															
05/21															X
05/23															X
05/24															X
06/18															X
06/19															X
06/20															X
Mesh Sizes**															
05/20															X
05/22															X
06/18															X
06/19															X

(continued)

TABLE 2 (continued)

Dates							STATION							
	P1	P2	P3	P4	P5	P6	P10	P11	P12	P13	P14	P15	P16	P17
Tow Length##														
05/20														X
05/21														X
06/18														X
06/20														X

---

*On each date in 1973 cooling system distributions were sampled near the bottom, mid-depth and surface; two samples at each depth for a total of 6 samples per station.

†On each date in 1974 and 1975 cooling system distributions were sampled at each station with 5 oblique tows from bottom to surface.

‡Transects were sampled with a combination of discrete-depth and oblique tows. On each date, each station was sampled with 3 oblique tows from bottom to surface and 2 samples each from bottom, mid-depth and surface for a total of 9 discrete samples.

#Five separate samples were taken with each kind of gear on each date sampled. Day and night comparisons were made with 5 samples each from bottom, mid-depth and surface for 15 samples during the day and 15 samples during the night on each date sampled.

**Five samples were taken with each mesh size on each date sampled.

##Five tows were made for each towing time tested on each date sampled.

was filtered through a 571-μ nylon net with a 1.8-liter bucket. Approximately $25m^3$ were processed in one hour. Five replicates were collected each sampling date.

The high-speed plankton sampler, described by Miller (1961), was towed initially at 0.5m/sec but that was decreased to about 0.2m/sec because larval fish extrusion was suspected from the high proportion of mutilated larvae in the samples. The sampler was mounted off the side of the boat and towed at a depth of 0.25 meters for 25 minutes. Approximately $22m^3$ were sampled at the reduced speeds. Five replicate tows were made on each sampling date.

The variation in catch with length of towing time was estimated with a 1-m, 571-μ net. A General Oceanics (Model 2030), digital flow meter was suspended in the center of all nets towed and all nets were outfitted with plastic, 1.8 liter buckets. Tows of 1, 2, 3, 4, and 5 minutes were made at the surface at station P17 (Fig. 2). An average of $35m^3$/min was sampled in the tows with no apparent variability related to towing time. Five replicates were made for each tow-length.

Capture rates of larval fish in 1-m nets of different mesh size were compared using 361-μ, 571-μ, 760-μ, and 1000-μ, nylon-mesh sizes. Five replicate samples were taken with each mesh size on each date. The nets were towed at 0.1m/sec at the surface for 3 minutes, filtering about $90m^3$ of water.

Samples of surface, mid-depth, deep (about 5-m deep and 1 to 2-m above bottom) and oblique tows were made at station P17 with a 571-μ net. Oblique tows were drawn at a constant rate to the surface from about the 5-m depth. Five, 1-min replicates (filtering about $33m^3$ of water) were made for each stratum sampled. The station was similarly sampled at night with surface, mid-depth, deep and oblique tows. In addition, during the day, a 571-μ net was towed on a bottom sled for 3 minutes at a speed of 0.2-m/sec. Approximately $31m^3$ of water were sampled (estimate based upon known speed and net area). Five replicates were collected on each date sampled.

A transect perpendicular to shore was sampled to define differences in larval fish densities at various distances from shore (Fig. 2). Four stations along the transect were sampled during the day with a 571-μ net. At each of the transect stations, three replicates were collected from the surface, three from deep water, and three with oblique tows from deep water to the surface. About $100m^3$ of water were sampled during a 3-min tow (1 m/sec). Stations P13, P14, P15, and P16, all along the transect, were 2, 6, 11, and 16 km from shore, respectively.

Tows with 571-μ mesh, 1-m nets were used during 1973, 1974, and 1975 to estimate larval fish abundance and distributions in the study area. Preliminary sampling was conducted at different depths in 1973 but it indicated no consistent, significant differences among surface, mid-depth, and deep samples (Nelson and Cole, 1975). Therefore, in 1974 and 1975 a 1-m, 571-μ nylon net was towed at an oblique angle through the water column at a constant rate from about 5-m deep to the surface for 2.5 min. Towing speed was approximately 1 m/sec. A 1.8 liter plankton bucket was attached and a general Oceanics (Model 2030) digital flow meter was fitted at the center of the net opening.

Two separate stations were sampled in the Raisin River channel (Fig. 2) to avoid the complex mixing in the short intake. The upstream river site (P7) was located about 1 km upstream from the plant intake. Another station (P6) was located at the mouth of the river to sample lake water that was drawn up the old river channel. Abundance at the intake (station P0) was calculated from concentratons at P6 and P7, which were weighed for river and lake volume-flow contributions to the cooling system. River-discharge rates were provided by the U.S.G.S. and plant pumping rates were provided by The Detroit Edison Company. Evaluations of water movements made during this study indicated that virtually all river water is drawn into the cooling system and the balance is made up by lake water. Samples also were taken from the upper (P2) and lower (P3) ends of the discharge canal, and 3 Lake Erie stations (P10, P11, and P12). The latter were sampled to assess the concentration and spatial variation of lake larval abundances.

Mortality was estimated at three stations within the immediate vicinity of the plant. Larvae were captured with a stationary, 1-m, 571-μ nylon net with a General Oceanics (Model 2030), digital, flow-meter suspended at its center. A modified (bolting cloth on the inside rather than the outside of the bucket) 582-μ, 1.8 liter bucket was attached to the net. The stationary net was set in a low velocity current of 1.15 to 0.25 m/sec to reduce mortality stemming from the technique and to ensure comparable sampling conditions at all sites. A reference station was sampled in the intake canal near station P0 to estimate combined natural and net-caused mortalities. The second station was located near P2 within 100-m of the out-fall from the concrete conduit into the discharge canal. Dead or dying larvae were separated from live animals by color and mobility. Translucent or mobile individuals were counted as alive while opaque, immobile ones were assumed to be dead. A field observation device, similar to one described by Marcy (1971), was used to maintain the ambient and elevated water temperatures around separation dishes while live larvae were counted.

All larvae collected were preserved in 5 percent formalin and later counted and identified to the most specific taxa possible. Rose-bengal dye was added to ease sorting. All samples were standardized to number per 100 m^3.

All data were tested for normality using the Shapiro-Wilk test (Gill, in press) and homogeneous variance using Bartlet's test. A log (x + 1) transformation was applied to all data to correct for non-normality. Then Bartlet's test was applied to the transformed data. Heterogeneous variance was usually indicated and a modified Scheffe's post-data test (Gill, 1971) was applied when applicable. Tukey's multiple range test was used to identify differences among means when departures from homogeneity were minor. It was applied to the technique comparisons, comparison of stations along the transect, and the comparisons among stations in 1975. Analysis of variance was applied to comparisons of day and night abundances.

SECTION 5

RESULTS

HYDRODYNAMICS AND WATER TEMPERATURES

The Lake

Currents in the lake were measured with drogues and a film recording current meter to assess the relative impact of wind on the direction and velocity of water movement. All studies in the lake were conducted near stations P10 and P11 (Fig. 2). The continuous film recording meters were placed about 5.0 m below the surface near the bottom and 2.5 m below the surface where they were partially protected from vandalism and storms. Instruments were lost to storms on two occasions and the film record was usable from a relatively small part of the time that instruments otherwise remained installed. The wind and water relationships in Table 3, B1 and B2 were derived from the retrieved record.

A significant ($p < .05$) regression between wind and water velocity and direction appeared at 2.5 m below the surface (Fig. C1) but not at 5 m. The velocities at 5 m were barely measurable; error probably precluded the identification of any relationship which may have existed. At 2.5 m, far from all of the variation in water velocity was explained by the wind. Part of the unexplained variation could have been effected by the length of the observation times that were compared. Water measurements were the means of instantaneous measurements made every 30 minutes during 9-hr spans. The data available for wind measurements were the means of instantaneous measurements of wind taken at the U.S. Weather Station (Toledo, Ohio) at 3-hr intervals over 9-hr spans. Improved estimates of the relationships might be determined from continuous records of wind and currents corrected for lags in the water response to wind change.

The current-meter recordings were compared to drogue estimates of water velocity and direction which were obtained from the Detroit Edison Company and reported in Cole (1976). These estimates were made at 3 depths (Table B2). Considerable difference existed in the estimates of water velocity made by drogues and current meters set at 2.5-m to 3-m depth; the metered velocities exceeded drogue estimates by nearly 4 times (Table 4). A range of possible velocities, calculated from the two techniques, is presented in Figure 3.

The current meter may have been a better estimator of horizontal velocity than drogues, based on limited observations from a current meter placed in the lower discharge canal at 1-m above the bottom in an area about 3-m deep. That meter recorded average velocities similar to the velocity which was calculated from pumping rates and the cross-sectional area in the canal.

TABLE 3. CALCULATED VOLUME-FLOW/SECOND BY VARIOUS TECHNIQUES IN DIFFERENT PARTS OF THE COOLING SYSTEM (numbers in parentheses indicate the number of replications)

Date	INTAKE			UPPER DISCHARGE		LOWER DISCHARGE	
	River Drogue	Lake Drogue	Drogue Sum for Intake	Gurley Meter	Probable Rate from Pump Ratings*	Drogue	Drogue
April 5, 1973				60 m^3	63 m^3		
June 11, 1973	23 m^3 (4)	38 m^3 (4)	61 m^3		63 m^3	17 m^3 (4)	33 m^3 (5)
June 12, 1973	20 m^3 (4)	35 m^3 (4)	55 m^3		63 m^3	46 m^3 (1)	23 m^3 (2)
June 13, 1973	-10 m^3 (4)	75 m^3 (5)	65 m^3		63 m^3		
August 10, 1973				68 m^3	63 m^3		
February 2, 1974				60 m^3	63 m^3		

*From the Detroit Edison Company. Pump records are incomplete and the actual numbers of pumps operating is unknown.

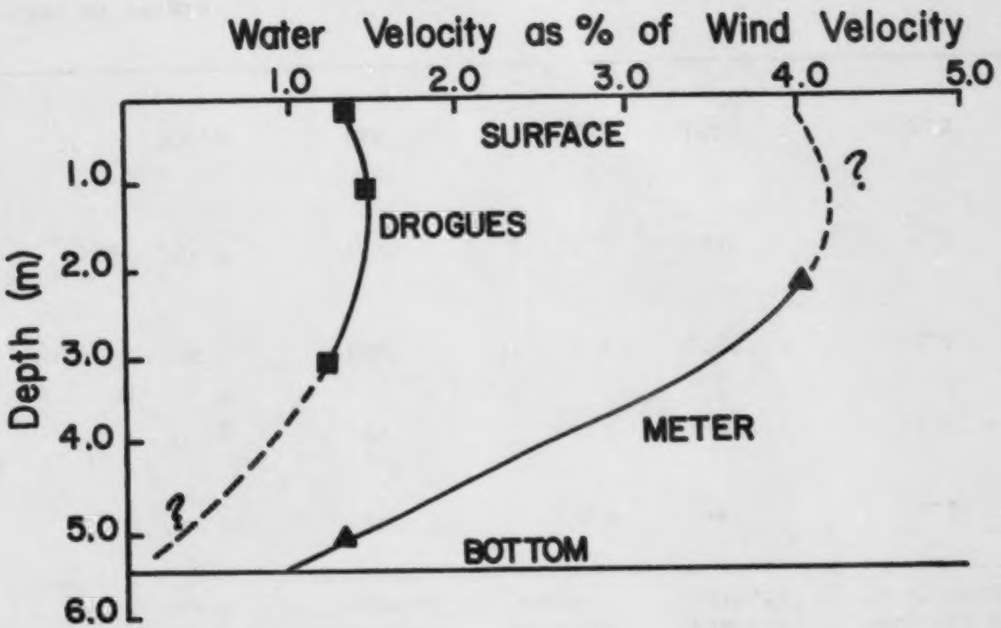

Figure 3. Relative water velocity at different depths in the study area near stations 2 and 3.

TABLE 4. DROGUE AND CURRENT METER ESTIMATES OF MEAN WATER VELOCITY AND RESULTANT DIRECTION

	n	Wind Velocity cm/sec	Wind Resultant Azimuth*	Water Velocity cm/sec	Water Resultant Azimuth*	Velocity as % of Wind	Deviation from Wind
Drogue 0m	5	678.4	74°	7.8	76°	1.3	-27°
Drogue# 1m	23	507.4	164°	6.7	146°	1.4	+ 8°
Drogue# 2m	20	556.2	154°	5.8	206°	1.1	+ 5°
Current meter† 2.5m	34	301.3	143°	12.2	143°	4.1	- 9°
Current meter† 5.0m	20	330.8	138°	4.1	189°	1.3	33°

*Direction of origin.
#Data from the Detroit Edison Company.
†General Oceanic Film Recording Current Meters.

Water velocities at the upper 3 meters seemed nearly uniform but velocity dropped rapidly from 3-m down to the bottom. Current directions for all depths averaged slightly to the right of the wind movements. Depth related velocity differences could profoundly effect plankton transport because different biases in vertical distributions will produce differential rates of horizontal movement through the basin. Some species could be more vulnerable to entrainment than others. A seasonal profile of water movements was calculated for Figure 4 from wind records at Toledo and a water velocity averaging 3 percent of wind velocity (from the drogue and current meter results). From day to day, water movements vacillated as unpredictably as the wind, but over a season, net water movements were northeastward nearly parallel to shore. This was generally true for all seasons and years included in the analyses. Therefore, the water and plankton in the study area frequently came from the Maumee Bay region to the south.

Although the resultant water movements at 1 to 2-km from shore were northward through the study area, the resultant movement of water immediately next to shore appeared to be southward. A sand pit along shore, just to the north of the discharge canal, has extended about 75 m into the discharge canal since the canal was constructed. A natural, sandy shoal extended southward from the mouth of the discharge canal, out into the basin more than 1 km from shore before it sharply dropped off to a bottom comprised of silty sediments. The thermal discharge emptied to the lake over the shoal and probably continued to maintain it as the Raisin River once did naturally.

The Raisin River

The river discharge was variable but typical of smaller, mid-western tributaries where the discharge in winter and spring months is 10 or more times the discharge in late summer or fall (Fig. 5). Mean monthly discharges have been recorded as high as 130 m /sec and as low as 1 m /sec. River discharge can change an order of magnitude in hours following storms and rapid thaws. The average annual river discharge is equivalent to 20 percent of the total cooling water demand, about 17 m /sec. The rest must be drawn from the lake. The proportion actually contributed by the river depends on the discharge at the time (Table 5). In winter and spring, the river contributed much more than it did in late summer. This variability in contribution affected the calculation of total annual entrainment of organisms in the study area because species composition in the river and lake differed. Most species of planktonic organisms were particularly vulnerable to entrainment for only a few weeks in the year; therefore, differences in species phenology may produce differences in the vulnerability of species to entrainment.

The Intake Region

Water from the river and lake mixed in the river channel and the intake before water was pumped through the condensers. Conductivity in the river channel was surveyed 4 times to document mixing (Fig. 6). River water was approximately twice as conductive as lake water on each survey although there were date-to-date differences in the conductivity. These data indicated that lake water could intrude up-river past the intake for nearly 1-km and river water could progress beyond the intake toward the lake at least 0.5-km. The distributions also indicated that little river water reached the lake; most, if not all, of the river must have been pumped into the cooling system on the dates sampled.

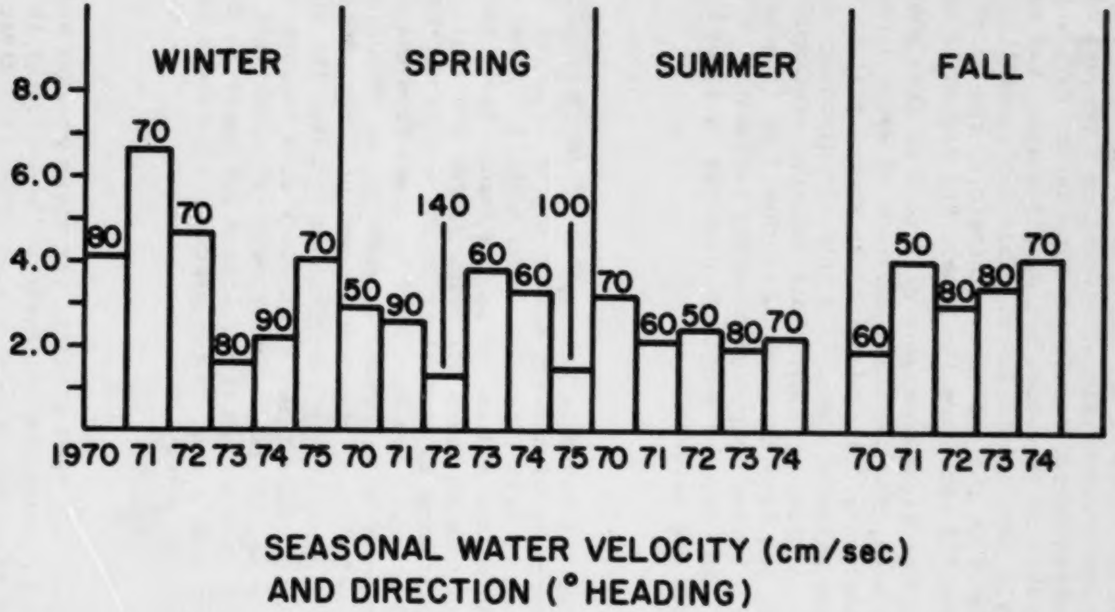

Figure 4. Mean daily resultant water velocity and direction calculated for each season from 1970 to 1975.

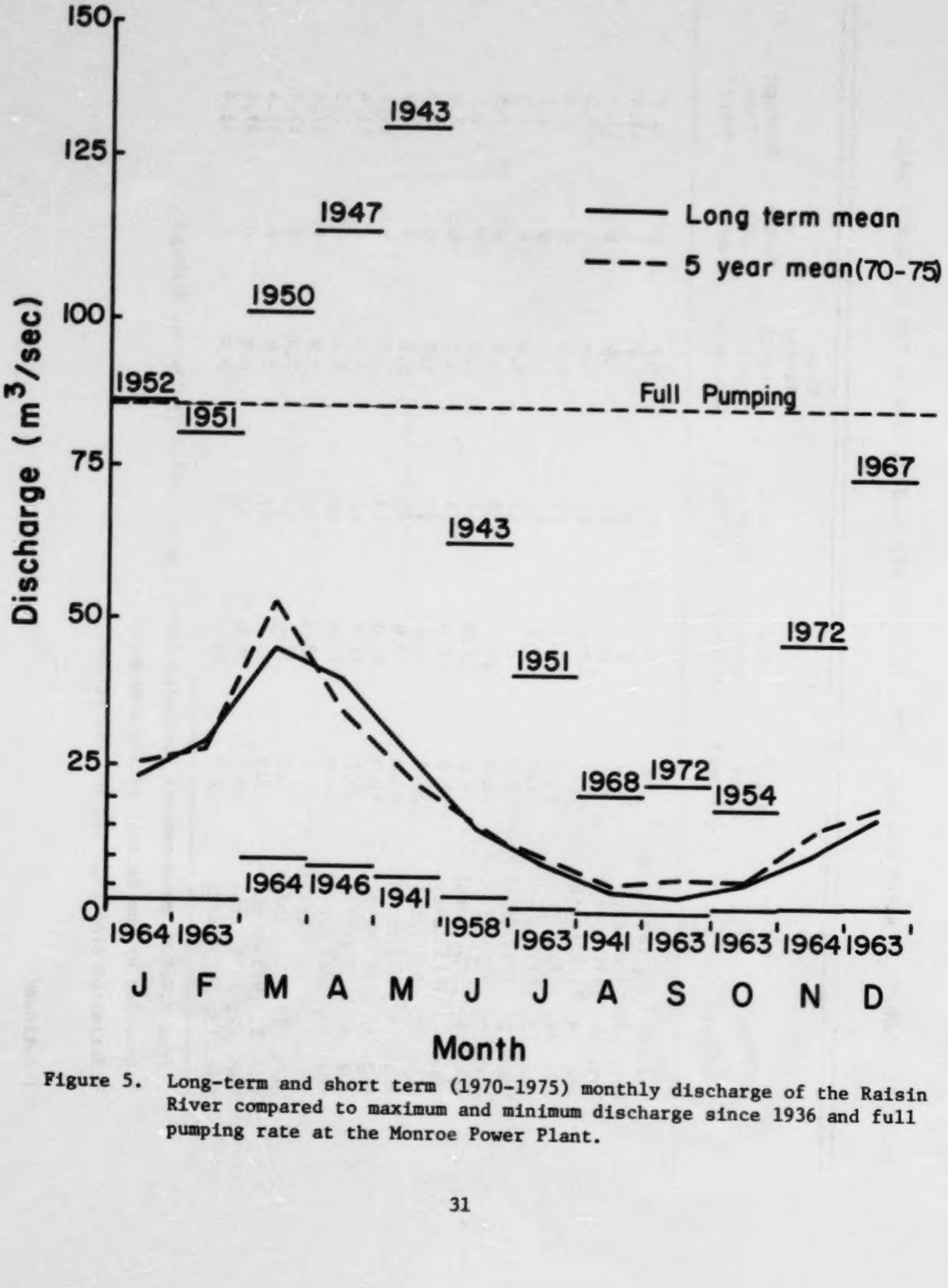

Figure 5. Long-term and short term (1970-1975) monthly discharge of the Raisin River compared to maximum and minimum discharge since 1936 and full pumping rate at the Monroe Power Plant.

TABLE 5. AMOUNTS OF RIVER AND LAKE WATER, VELOCITY AND PASSAGE TIME IN THE DISCHARGE CANAL

Date	River* Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)	Mean Velocity (cm/sec) Upper Discharge	Number of Pumps	Passage Time (hrs)
Nov. 9, 1972 (eve)	57.4	0	42	3.9	6†	11.4
Nov. 10, 1972 (aft)	52.0	0	42	3.9	6	11.4
Nov. 10, 1972 (morn)	49.0	0	42	3.9	6	11.4
Jan. 18, 1973 (eve)	17.4	45.6	63	3.9	9	7.5
Jan. 24, 1973 (aft)	42.2	20.8	63	5.8	9	7.5
Jan. 25, 1973 (morn)	44.0	19.0	63	5.8	9	7.5
March 30, 1973 (eve)	63.0	0	63	5.8	9	7.5
April 5, 1973 (aft)	43.0	20.0	63	5.8	9	7.5
April 6, 1973 (morn)	38.0	25.0	63	5.8	9	7.5
June 11, 1973 (eve)	22.0	41.0	63	5.8	9	7.5
June 12, 1973 (aft)	20.0	43.0	63	5.8	9	7.5
June 13, 1973 (morn)	23.0	40.0	63	5.8	9	7.5
Aug. 8, 1973 (eve)	11.0	31.0	42	3.9	6	11.4
Aug. 9, 1973 (aft)	10.5	31.5	42	3.9	6	11.4
Aug. 10, 1973 (morn)	12.0	30.0	42	3.9	9‡	7.5
Sept. 2 , 1973 (eve)	3.7	38.3	42	3.9	6	11.4
Sept. 29, 1973 (aft)	5.0	37.0	42	3.9	6	11.4
Oct. 1, 1973 (morn)	7.0	35.0	42	3.9	6	11.4
Dec. 12, 1973 (eve)	12.2	30.0	42	3.9	6	11.4
Dec. 13, 1973 (aft)	12.8	29.4	42	3.9	6	11.4

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* From U.S.G.S. measurements corrected for 1.5 m/sec added by Monroe, Michigan.

† Recorded by the Detroit Edison Company.

‡ Estimated from chloride concentrations.

(continued)

TABLE 5 (continued)

Date	River* Water (m^3/sec)	Lake Water (m^3/sec)	Total Discharge (m^3/sec)	Mean Velocity (cm/sec) Upper Discharge	Number of Pumps	Passage Time (hrs)
Jan. 31, 1974 (eve)	123.3	0	42	3.9	6	11.4
Feb. 1, 1974 (aft)	102.3	0	42	3.9	6	11.4
April 7, 1974 (eve)	96.6	0	42	3.9	6	11.4
April 8, 1974 (aft)	94.7	0	42	3.9	6	11.4
June 11, 1974 (eve)	16.6	60.8	77	7.1	11	6.3
June 12, 1974 (aft)	16.2	61.3	77	7.1	11	6.3
Aug. 14, 1974 (eve)	6.6	70.8	77	7.1	11	6.3
Aug. 15, 1974 (aft)	6.1	64.3	70	6.4	10	7.0
Oct. 19, 1974 (eve)	4.9	44.4	49	4.5	7	9.9
Oct. 21, 1974 (aft)	4.6	51.8	56	5.2	8	8.6
Jan. 24, 1975 (eve)	17.3	32.0	49	4.5	7	9.9
Jan. 25, 1975 (aft)	17.5	38.8	56	5.2	8	8.6
March 16, 1975 (eve)	26.0	16.3	42	3.9	6	11.4
March 15, 1975 (aft)	25.8	30.5	56	5.2	8	8.6
May 16, 1975 (eve)	17.6	17.6	35	3.2	5	14.0
May 17, 1975 (aft)	16.7	17.6	35	3.2	5	14.0
July 27, 1975 (eve)	4.8	79.7	84	7.8	12	5.7
July 28, 1975 (aft)	4.6	79.9	84	7.8	12	5.7
Sept. 15, 1975 (eve)	12.2	72.3	84	7.8	12	5.7
Sept. 16, 1975 (aft)	12.5	72.0	84	7.8	12	5.7

* From U.S.G.S. measurements corrected for 1.5 m/sec added by Monroe, Michigan.

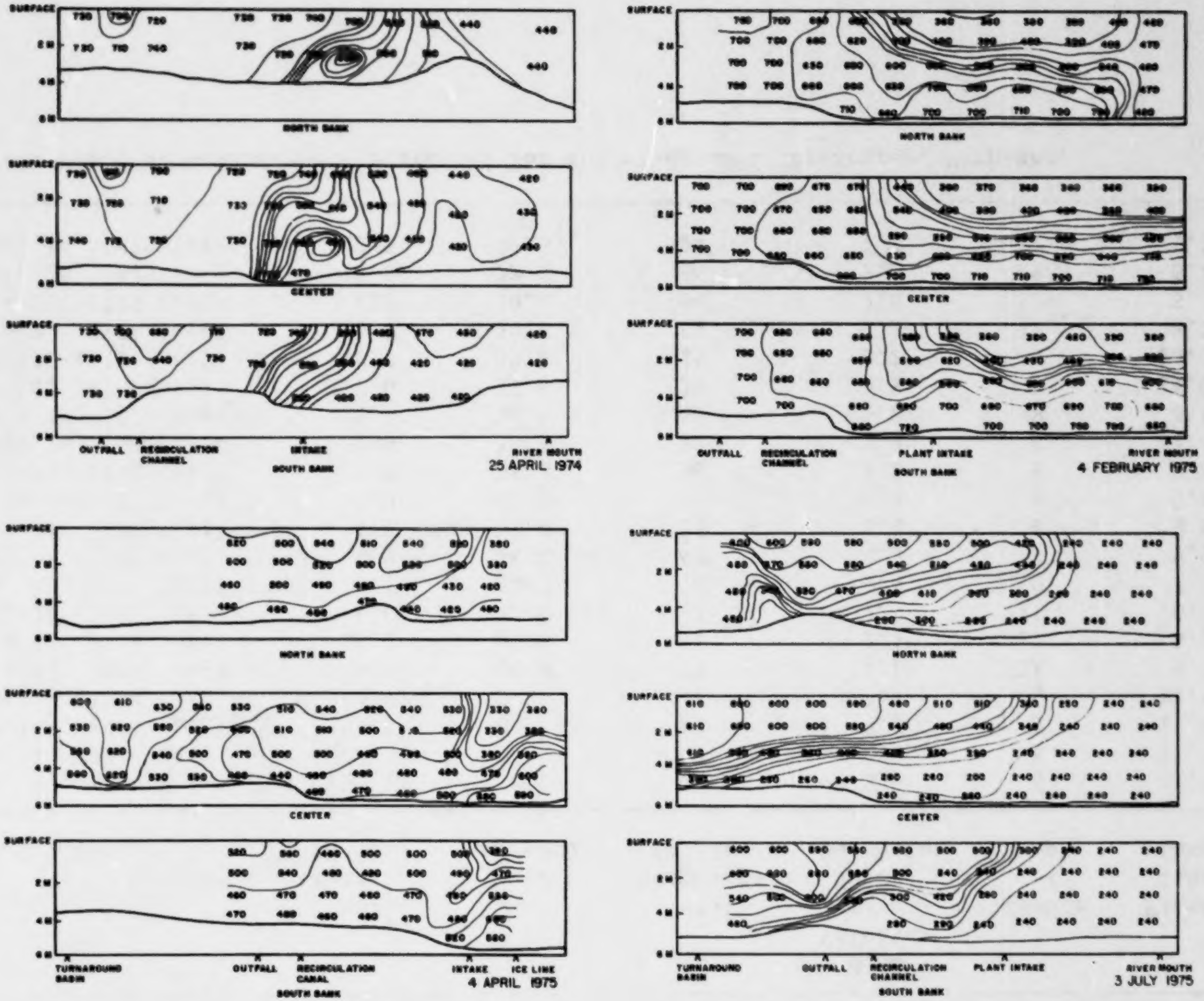


Figure 6. Conductivity in the intake region of the Raisin River.

Chloride profiles made at stations 17 and 9 confirmed the complexity of mixing in the river channel (Fig. 7). The water in the river channel often was vertically homogenous but lake water intruded upstream into the river water about 25 percent of the time. Intrusions occurred at various depths, and were not related simply to thermal differences in the water masses. Only on 4 percent of the occasions examined did river water reach the river mouth (station 17). The chloride distribution reinforced our belief that most (90 to 100%) of the river water was pumped through the condenser except when the river discharge exceeded pumping demands.

Discharge Canal and Plume

The discharge canal, as expected, was almost vertically well-mixed, but horizontal variations between stations 12 and 8 were great enough (greater than 3 mg/liter in 15 percent of the measurements) to indicate that an important water mass transition could occur within a few hours (Tables 6, B3). The flow time between stations 12 and 8 usually was less than 5 hours. These rapid transitions probably influenced the precision of predictions for the mixing of lake and river water in the intake at station 18 because the flow times between stations 9 and 17 and station 18 were similar to the flow time between stations 12 and 8. Errors in measurements from the same water sample were usually about 5 percent. On any particular day, expected differences between the predicted mixture of lake and river water (from stations 9 and 17) at station 18 would vary from that at station 12 by 1 to 2 mg/liter and, occasionally, by 4 or 5 mg/liter. These variations were too great to enable reasonable estimates of source-water proportions on any particular date. But, annual means averaged out the daily variation and provided a reasonable estimate of average conditions.

Table 7 summarizes the results of two different approaches used to estimate the average annual proportions of river (9) and lake (17) water in the intake and discharge flow. For the first approach, chloride and total solids, were used as tracers to separately estimate proportions of lake and river water. In the second case, the pumping rate, reported by Detroit Edison, and the river discharge, reported by the U.S.G.S. (corrected for additions from the City of Monroe), were used to calculate the amount drawn in from the lake, assuming that the river was totally pumped through the condenser and lake water comprised the balance. This method could only be applied to dates when pumping rates were actually measured by the company. Pumping rates were not recorded for about one third of the sampling dates. The only available estimates were calculated from the chemical tracers measured in the cooling system and the pumping rates reported for the closest dates.

The mean annual averages estimated by both techniques (Table 7) indicate that, most if not all, river water was pumped through the condensers as expected from profiles of chloride and conductivity in the river channel. In fact, the river contribution appeared to be slightly underestimated. This could have been caused by a slight underestimate of river flow since U.S.G.S. measurements came from 10-km upstream and, although corrections were made for water additions from the City of Monroe (1.5 m^3/sec), no corrections were made for other additions over the 10-km reach.

Using tracers (Tables B3, B5, B6), differences in the properties of the source waters were calculated for stations in the intake and the discharge canal.

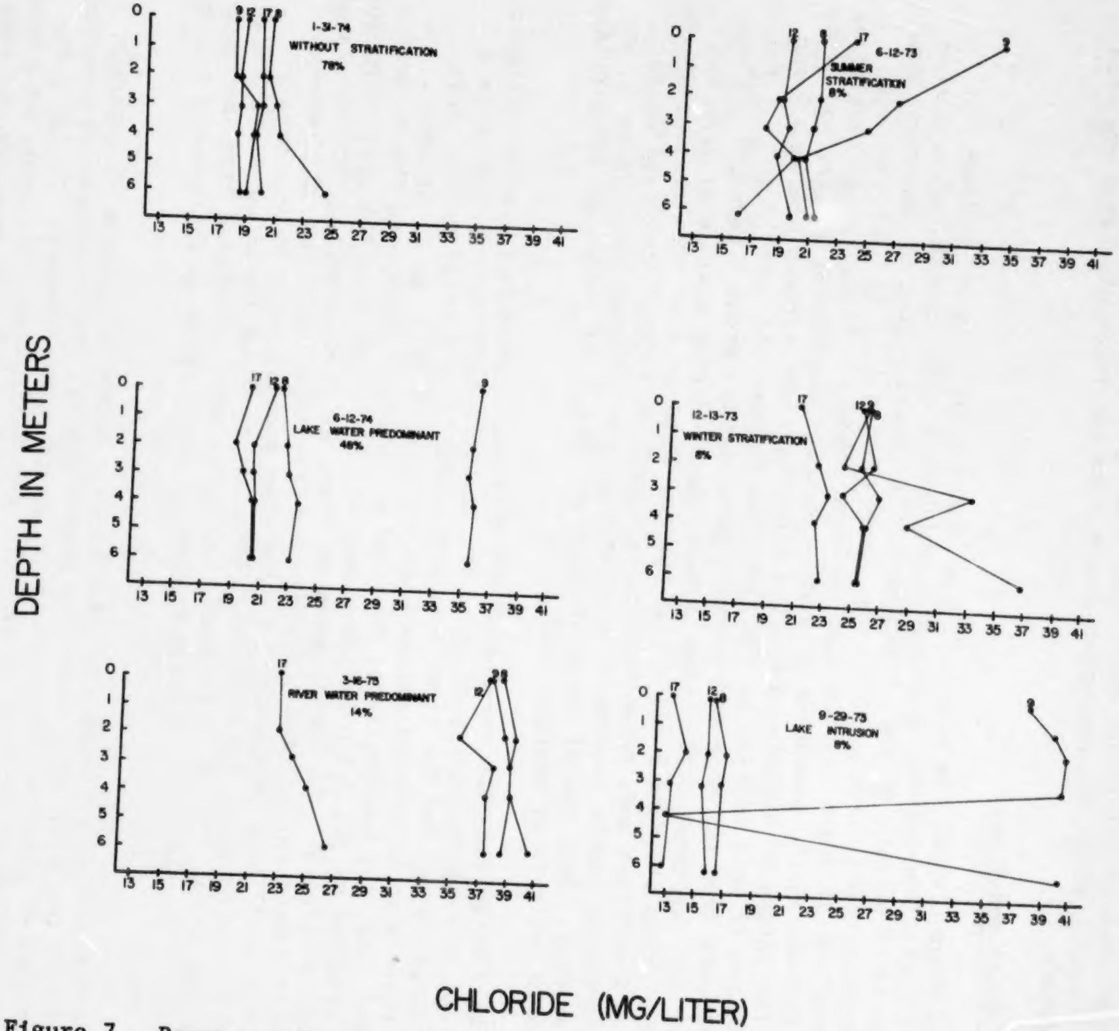


Figure 7. Representative categories of chloride profiles in the cooling system of the Monroe Power Plant with percentage of time that each of the conditions accrued.

TABLE 6. MEAN ANNUAL CONCENTRATION OF CHLORIDE, DISSOLVED SOLIDS, AND TOTAL SOLIDS (mg/liter)

	17	9	18	12	8	14	15	16
Chloride								
1973[*]	21.4	29.4	25.0	25.0	25.6	26.0	22.8	20.6
1974[*]	19.9	31.7	22.7	23.3	23.3	23.2	20.6	18.7
1975[@]	21.3	32.2	24.4	26.1	26.5	26.5	24.8	23.4
Grand Mean	20.9	31.1	24.1	24.8	25.1	25.2	22.7	20.9
Dissolved Solids								
1973[†]	304.4	385.7	344.2	341.4	347.7	365.2	296.6	244.0
1974[†]	243.4	398.5	275.0	316.2	302.0	305.0	235.0	208.1
1975[‡]	222.1	361.4	268.5	294.2	317.5	301.8	280.3	238.1
Grand Mean	256.6	381.9	295.9	317.3	322.4	324.0	270.6	230.1
Total Solids								
1973[*]	293.1	433.5	372.2	386.9	389.2	418.6	331.0	282.4
1974[*]	286.3	412.4	311.3	332.4	338.9	341.7	286.1	241.9
1975[@]	252.5	457.6	319.1	342.9	362.2	360.8	307.9	283.4
Grand Mean	277.3	434.5	334.2	354.1	363.4	373.7	308.3	269.2

[*] Mean for each station was calculated from 90 samples.

[@] Mean for each station was calculated from 75 samples.

[†] Mean for each station was calculated from 30 samples.

[‡] Mean for each station was calculated from 25 samples.

TABLE 7. MEAN RIVER WATER CONTRIBUTION CALCULATED FROM CONCENTRATIONS OF CHEMICAL TRACERS* AND U.S.G.S. MEASURES OF RIVER DISCHARGE¶ AND PLANT PUMPING RATES†
(percent)

	Station and Measure						
	Chloride		Total Solids		Dissolved Solids		U.S.G.S. and Pumping Rate†
Year	12	8	12	8	12	8	
1973	30.3	36.3	27.2	37.1	28.3	38.2	34.7
1974	30.1	29.4	29.3	28.9	38.5	32.0	20.0
1975	39.4	42.1	39.7	46.8	53.3	52.4	26.2
Mean Annual	33.3	35.9	32.1	37.6	36.7	40.8	26.9

*Only those dates when both the river and lake contributed water were used for the calculations.

¶U.S.G.S. measurements of river discharge were taken 11 km upstream from the intake.

‡Pumping rates were obtained from records of the Detroit Edison Company.

†For this calculation it was assumed that all river water was drawn into the intake and the balance came from the lake.

An intake station (18) was calculated for the mixed concentrations of all compounds and organisms sampled at stations 9 and 17. These estimates were influenced by at least the same variability in water masses reflected by chloride concentrations. Therefore, differences in the cooling system on any single day were, by themselves, considered to be relatively meaningless in terms of cooling system effects. Seasonal or annual differences on the other hand were considered more reliable indicators of cooling-system impact because they averaged out random spatial variation.

In the plume, chloride, total solids and dissolved solids all were diluted to about the same proportions as temperature, the criterion used to choose the sampling sites in the plume. Based on these tracers, most of the waste heat is mixed into the receiving waters rather than the atmosphere.

TEMPERATURE

Ambient water temperatures in the study are a closely followed meteorological change (Fig. 8). We never observed any sharp changes in water temperature that could have originated with upwellings of hypolimnetic waters, nor was a thermal bar ever observed. The temperatures in the lake and Raisin River usually varied by 1 to 2°C except in mid-winter when all water temperatures approach 0°C (Table 8). The annual thermal cycle in the river and lake basically were similar before they mixed in the intake to the plant condenser.

Winter temperatures were elevated as high as 17°C above ambient during condenser passage but elevations during other seasons rarely exceeded 10°C. The temperature elevation at the condenser varied as a function of power generation and the amount of water pumped. Both varied widely over the study period, therefore, temperature elevations ranged from 0 to 17°C. The discharge was usually close to homothermous through its length. Exceptions to this probably resulted from fluctuating heat-rejection rates. Less than 10 percent of the waste heat carried by the discharge canal was lost before the water reached the lake (Table 8).

The thermal plume spread over a sandy shoal at the mouth of the discharge canal; the largest plume measured by the Detroit Edison Company during the study period was about 860 hectares (The Detroit Edison Co., 1976). The location of the plume varied with the direction and velocity of the wind and the rate of thermal discharging. Our observations indicated that the outer edge moved from 4-km south of the discharge-canal mouth to about 1-km north of the mouth of the Raisin River. Profiles measured in the plume at stations 15 and 16 indicated that the plume was usually mixed well vertically (Table B7). The greatest vertical variation occurred at times when stratification also occurred under ambient conditions in the lake at station 17. The combination of consistent winds and shallow water seemed to maintain homeothermy within the plume.

OXYGEN

In winter, the intake waters of the river and lake typically were saturated to slightly supersaturated with oxygen at all depths (Tables 9; B7). As the season warmed, diurnal variation in the percent saturation of oxygen increased

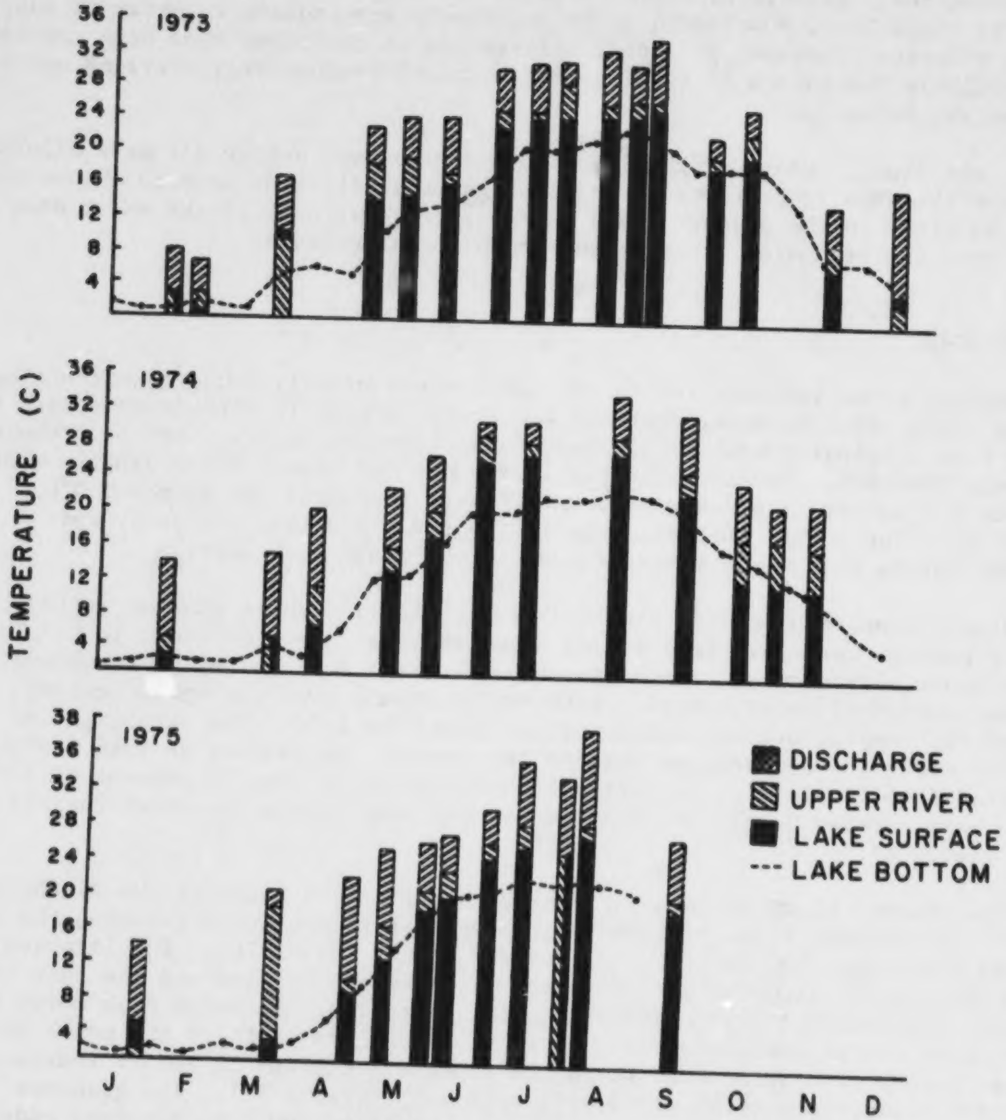


Figure 8. Surface temperatures in the Raisin River and discharge canal compared to nearby lake temperatures at bottom and surface during the study period.

TABLE 8. MEAN AND MAXIMUM TEMPERATURES IN WARM AND COOL SEASONS RECORDED DURING THE STUDY

(C°)

	Mean Ambient		Mean Discharge		Mean Elevation	Maximum Lake (17)	Maximum Elevation	Maximum Discharge (12)
	Lake (17)	River (9)	(12)	(14)				
1972-1973								
Nov-March	6.3	7.3	13.9	11.4	6.6	9.0	10.0	19.0
April-Sept	18.3	19.1	24.3	24.1	5.9	27.5	9.0	31.0
1973-1974								
Oct-March	8.4	9.0	18.6	15.9	9.6	10.0	17.0	21.0
April-Sept	20.0	20.8	27.5	26.4	7.5	26.0	10.0	35.5
1974-1975								
Oct-March	5.3	9.7	17.9	16.9	8.7	12.0	10.0	21.7
April-Sept	18.6	19.6	28.5	27.1	9.9	26.7	13.0	35.0

TABLE 9. OXYGEN PERCENT SATURATION IN THE COOLING SYSTEM

Time	STATION 17			9			12			8			14		
	M*	A	E	M	A	E	M	A	E	M	A	E	M	A	E
Nov-Apr															
Surface															
1973	102	97	91	104	99	90	113	108	111	111	103	109	110	100	104
1974	82	106	103	74	104	111	90	120	120	81	107	114	85	104	106
1975	100	98	105	119	107	139	130	114	117	117	100	110	104	101	103
Mean	95	100	100	99	103	113	111	109	116	103	103	111	100	102	104
Bottom															
1973	100	96	89	100	94	90	113	98	105	109	102	99	106	101	99
1974	78	95	104	43	102	102	90	109	109	72	109	104	86	91	104
1975	98	99	99	97	93	99	129	118	117	94	93	96	94	96	100
Mean	92	97	97	80	96	97	111	108	110	92	98	100	95	96	101
Grand Mean	93	99	99	90	100	105	111	109	113	97	101	105	98	99	103
May-Oct															
Surface															
1973	75	88	85	52	62	76	67	82	84	65	85	76	64	82	89
1974	80	99	160	54	68	101	84	85	175	82	86	158	82	86	147
1975	118	122	108	107	115	93	129	124	117	119	122	110	121	116	126
Mean	91	105	118	71	82	90	93	97	125	89	98	115	89	95	121
Bottom															
1973	56	72	71	14	28	49	64	78	76	59	72	66	58	67	83
1974	75	86	156	39	50	16	80	90	175	75	67	33	75	65	140
1975	110	115	91	97	91	84	124	127	113	108	114	96	67	113	111
Mean	80	91	106	50	56	50	89	98	121	81	84	65	67	82	111
Grand Mean	86	97	112	61	69	70	91	98	123	85	91	90	77	88	116
Grand Annual Mean	90	98	105	75	84	88	101	103	118	91	96	98	88	94	109

* M = morning; A = afternoon; E = evening.

in amplitude, probably in response to increased photosynthesis during the day and increased community respiration at night. The expected pattern of high daytime and low nighttime concentrations materialized irregularly (Table 9), presumably because of time lags and changes in water masses passing by the fixed stations.

In summer, oxygen demand near the lake bottom was high enough to reduce oxygen concentrations to 50 percent saturation. Very low concentrations occurred near the river bottom in summer, 1973, they appeared to be higher in 1974 and 1975, perhaps because of improved waste treatment at Monroe, Michigan. In winter, primary productivity was low, the source waters were near saturation before they passed through the condenser, and the percent of oxygen saturation commonly increased 10 to 20 percent with temperature elevation. Condenser passage tended to mix oxygen concentrations uniformly from surface to bottom and increase the percent saturation. During warmer months, the overall change was relatively samll (Table 8), but winter values increased substantially. The highest percent saturation (175%) occurred in August, 1974, probably as a consequence of high primary productivity throughout the study area. Relatively little change occurred in this water mass as it passed through the cooling system.

The percent saturation of oxygen in the discharge canal usually decreased as the water flowed to the lake. Declines seemed slightly stronger at the bottom than at the surface. Thermal stratification in the plume did not commonly cause extreme oxygen reduction beneath the plume. In fact, oxygen concentrations in the plume were very similar to those observed in the lake-source waters. The lowest concentration observed near bottom in the plume was 4.0 mg/liter (43 percent saturation) at a time when the lake concentration near the bottom was 3.1 mg/liter (32 percent). Because of warm, calm weather on that date, temporary stratification occurred throughout the study area. If anything, power plant operation may have reduced the impact of natural stratification on aquatic communities.

SUSPENDED SOLIDS

Concentrations of suspended solids in the lake and river tended to be highest in winter and spring (Fig. 9). Neither of the lake or river sources were consistantly more turbid with suspended solids (Table 10; B8). River concentrations often fluctuated differently from lake concentrations. Boat traffic may have been responsible for a particularly high river concentration on March 17, 1975 (193 mg/liter), which was six times the average concentration.

The predicted intake concentrations closely matched the observed concentrations in the upper discharge canal. This was expected because there was little erodable surface between the intake and upper discharge canal. Between the upper and lower stations in the discharge canal, suspended solids increased a mean of 20 percent over the three years, apparently because of erosion from the canal walls. Based on the chloride tracer, concentrations of suspended solids in the plume should have been diluted to 60 percent of the discharge canal concentrations compared to a realized dilution of 32 percent. This could have been caused by turbulence over the shoal at the mouth of the discharge canal which resuspended solids from the bottom until water masses moved out to deeper water and the solids settled down to ambient concentrations. Concentrations at the plume edge indicate that suspended solids there were diluted like chloride.

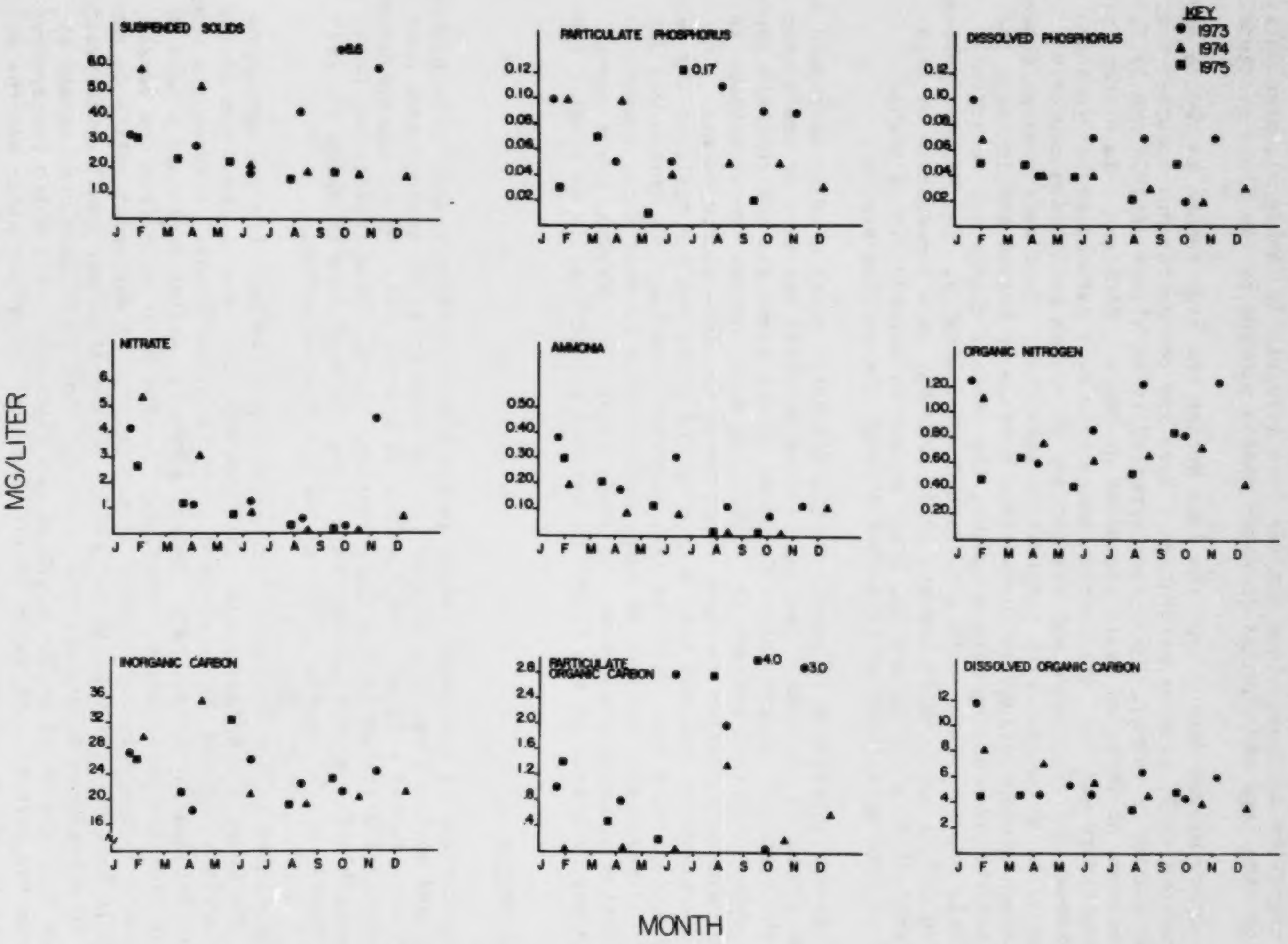


Figure 9. Temporal variation of chemical concentration selected for study in the lake source used for cooling water at the Monroe Power Plant.

TABLE 10. MEAN ANNUAL CONCENTRATION[*] OF SUSPENDED SOLIDS, PHOSPHORUS, NITROGEN, AND CARBON IN THE COOLING SYSTEM OF THE MONROE POWER PLANT (mg/liter)

		17	9	18	12	8	14	15	16
Suspended Solids	1973[¶]	44.8	32.7	41.2	42.2	40.6	46.1	47.6	39.9
	1974[¶]	31.4	32.2	29.8	35.9	43.0	43.7	47.5	33.2
	1975[†]	22.7	67.9	45.8	32.1	39.1	41.9	26.1	26.9
Three-year Mean		33.0	44.3	38.7	36.7	40.9	43.9	40.4	33.3
Chloride Prediction[‡]					39.9	40.3	40.4	36.4	33.5
Total Phosphorus	1973	.14	.19	.17	.17	.18	.17	.15	.12
	1974	.10	.19	.12	.14	.16	.13	.13	.08
	1975	.10	.22	.15	.13	.13	.14	.11	.08
Three-year Mean		.11	.20	.15	.15	.16	.15	.13	.09
Chloride Prediction					.15	.15	.15	.13	.12
Particulate Phosphorus	1973	.08	.08	.08	.08	.09	.09	.08	.07
	1974	.06	.09	.07	.07	.10	.09	.09	.05
	1975	.06	.10	.09	.04	.03	.05	.05	.03
Three-year Mean		.07	.09	.08	.06	.07	.08	.07	.05
Chloride Prediction					.08	.08	.08	.07	.06

[*] See Appendix for daily mean values.

[¶] The mean of five replicates for each of six dates; a total of 30 samples.

[†] The mean of five replicates for each of five dates; a total of 25 samples.

[‡] The chloride prediction is the expected concentration from mixing alone using chloride as an internal tracer.

(continued)

TABLE 10 (continued)

		17	9	18	12	8	14	15	16
Dissolved Phosphorus	1973	.06	.11	.09	.09	.09	.08	.07	.05
	1974	.04	.10	.05	.07	.06	.06	.04	.03
	1975	.04	.12	.06	.09	.10	.09	.06	.05
Three-year Mean		.05	.11	.07	.08	.08	.08	.05	.04
Chloride Prediction					.08	.08	.08	.07	.06
Total Non-gaseous Nitrogen	1973	3.21	4.60	4.21	4.45	4.39	4.40	3.55	2.31
	1974	2.52	3.84	2.93	3.17	2.90	3.14	1.95	1.46
	1975	1.78	3.65	2.37	2.84	2.83	2.96	2.50	2.36
Three-year Mean		2.50	4.03	3.18	3.49	3.37	3.50	2.67	2.04
Chloride Prediction					3.25	3.31	3.34	3.00	2.77
Nitrate Nitrogen	1973	2.00	3.21	2.93	2.96	3.22	2.94	2.23	1.41
	1974	1.69	2.34	1.97	2.07	2.05	2.02	1.02	.73
	1975	1.07	2.10	1.46	1.83	1.78	1.86	1.49	1.40
Three-year Mean		1.59	2.55	2.13	2.29	2.35	2.27	1.58	1.18
Chloride Prediction					2.21	2.25	2.27	2.04	1.88

(continued)

TABLE 10 (continued)

	17	9	18	12	8	14	15	16
Ammonia Nitrogen 1973	.20	.37	.27	.43	.38	.33	.25	.16
1974	.09	.27	.11	.18	.17	.17	.11	.06
1975	.14	.38	.19	.19	.19	.22	.15	.10
Three-year Mean	.14	.34	.19	.27	.25	.24	.17	.11
Chloride Prediction				.20	.20	.20	.18	.17
Organic Nitrogen 1973	1.00	.45	.75	1.08	1.00	1.03	.78	.72
1974	.74	1.23	.84	.92	.93	.95	.91	.74
1975	.58	1.16	.73	.82	.85	.89	.87	.86
Three-year Mean	.77	1.14	.86	.95	.94	1.00	.85	.78
Chloride Prediction				.89	.91	.92	.83	.76
Total Organic Carbon 1973	7.8	8.9	8.4	8.6	8.3	8.4	7.2	6.4
1974	5.9	8.3	6.4	6.9	8.1	7.4	6.9	5.8
1975	6.2	10.1	7.9	7.5	7.3	7.4	6.6	6.4
Three-year Mean	6.6	9.1	7.5	7.7	7.9	7.8	6.9	6.2
Chloride Prediction				7.6	7.6	7.7	6.9	6.3

(continued)

TABLE 10 (continued)

		17	9	18	12	8	14	15	16
Total Inorganic	1973	23.4	33.2	28.3	28.8	29.5	29.2	25.4	21.4
Carbon	1974	24.7	37.9	27.4	30.6	29.2	28.8	24.5	21.5
	1975	24.5	38.3	28.9	30.0	29.5	29.7	25.8	22.1
Three-year Mean		24.2	36.4	28.2	29.8	29.3	29.2	25.2	21.7
Chloride Prediction					29.3	29.8	30.1	27.0	25.0
Particulate	1973	1.6	1.4	1.5	2.2	2.3	2.6	2.5	2.3
Organic Carbon	1974	0.4	0.9	0.6	1.0	0.9	1.1	1.0	1.4
	1975	1.7	3.9	2.8	2.0	2.3	2.9	2.0	2.4
Three-year Mean		1.2	2.1	1.6	1.8	1.8	2.2	1.8	2.0
Chloride Prediction					1.7	1.7	1.8	1.6	1.5
Dissolved	1973	6.2	7.5	6.9	6.4	6.0	5.8	4.7	4.1
Organic Carbon	1974	5.5	7.4	5.8	5.9	7.2	6.3	5.9	4.4
	1975	4.5	6.2	5.1	5.5	5.0	4.5	4.6	4.0
Three-year Mean		5.4	7.0	5.9	5.9	6.1	5.6	5.1	4.2
Chloride Prediction					6.1	6.2	6.3	5.7	5.2

CARBON

Neither dissolved organic carbon or total inorganic carbon varied with a seasonally regular pattern (Fig. 9). Particulate carbon varied erratically all year but was frequently most concentrated during the warm growing season from April through September.

Only minor differences occurred among the station means in the cooling system. Both organic and inorganic carbon fractions in the river exceeded respective lake concentrations (Table 10; B9; B10; B11); 66 percent in the aggregate. But because the greatest carbon concentrations occurred in warm months when river discharge was least, lake concentrations dominated the annual rate of carbon transport through the cooling system. Certain changes within the cooling system consistantly emerged each year, but variation from sampling date to sampling date confounded statistical determination of differences among stations in the cooling system.

Total carbon concentrations hardly changed (less than 5% increase) as water passed from the intake to the upper discharge canal, in close agreement with slight changes in concentrations of chloride and dissolved solids. Condenser passage caused no immediate response, and total organic carbon fluctuated slightly about a stable concentration as water passed down the discharge canal. But the concentration of particulate organic carbon consistantly increased as dissolved organic carbon decreased. Total inorganic carbon concentrations behaved like chloride in the discharge canal.

Once the water entered the lake plume, the concentration of particulate organic carbon remained higher and the dissolved organic carbon declined more than anticipated by the dilution predicted from chloride concentrations. The decline of dissolved carbon slightly exceeded the gain of particulate carbon by an average of 0.3 mg/liter (5%). Both total carbon and total inorganic carbon concentrations declined more (10% mean) than anticipated by simple dilution. The total carbon loss from the cooling system was small and only identifiable because of the consistency of results from year to year.

PHOSPHORUS

Phosphorus concentrations in the source waters varied erratically; both particulate and dissolved phosphorus fluctuated irregularly with no indication of seasonally related changes (Fig. 9). River concentrations averaged nearly twice the lake concentrations (Table 10; B12; B13; B14), but the total river contribution during most of the growing season was much less than the lake contribution.

Mean phosphorus concentrations revealed no consistent changes within the cooling system. Similar concentrations occurred at all stations within the intake and discharge canal. However, at the high concentrations observed, and the precision used, changes caused by biological activity could take place without materializing in the data. In the plume, phosphorus concentrations declined more than predicted from chloride concentrations. Presumably, phosphorus precipitated from the water column as the thermal discharge mixed with lake water. Both particulate and dissolved concentrations behave similarly.

NITROGEN

Total nitrogen usually was most concentrated in the lake during winter and spring (Fig. 9). This reflected high winter and spring concentrations of nitrate-nitrogen and ammonia-nitrogen; both regularly declined to relatively low summer and fall concentrations. Unlike inorganic nitrogen, the concentration of organic-nitrogen varied unpredictably, but the ratio of organic and inorganic nitrogen peaked sharply in late summer and early fall when inorganic nitrogen was relatively dilute and organic nitrogen was particularly concentrated.

Total, nongaseous nitrogen changed insignificantly as water passed through the condenser and the discharge canal. In the plume, it usually declined more than predicted by simple dilution (Table 10; B15). Unlike any other substance examined, ammonia-nitrogen rapidly increased as water passed through the short section from the intake to the discharge canal (Table 10; B16). Once water reached the discharge canal, both nitrate-nitrogen and ammonia-nitrogen declined slightly more than explained by simple dilution while organic nitrogen increased a complementary amount (average of 0.05 mg/liter)(Table 10; B16; B18). The ratio of the average increase in organic nitrogen to the average increase in particulate organic carbon was 0.1.

Carbon and nitrogen may have been photosynthetically fixed as water passed down the canal. The average changes in nitrogen concentrations were less than 10 to 20 percent and impossible to define precisely with the existing variability, but the year to year trends indicated consistantly integrated biogeochemical changes while water passed through the cooling system. As indicated by these changes, slightly more organic matter was decomposed than was fixed during passage through the cooling system. There appeared to be little regeneration of inorganic nitrogen in the process. In fact, inorganic nitrogen tended to decrease more than could be incorporated in algae as organic nitrogen.

PHYTOPLANKTON

The phytoplankton assemblage was species rich but most taxa were rare. About 20 species accounted for over 90 percent of the phytoplankton density. The Bacillariophyceae, Chlorophyceae and Cyanophyceae predominated over lesser densities of Cryptophyceae, Dinophyceae, Euglenophyceae, Chlorobacteriae and Chrysophyceae (Table 11; B19; B20). The yearly mean density of all algae sampled in the lake at station 17 varied from 6691.4/ml in 1973 to 14,755.6/ml in 1975. This annual fluctuation was caused mostly by the relatively great variability of blue-green algae. The other important algal classes were more stable.

Vertical distributions in the cooling system were very consistant (Table 12); nearly constant from top to bottom. The phytoplankton were well-mixed throughout the sampled water column.

Yearly mean densities were similar in the lake and river sources in 1973 when blue-green algae were uncommon in both areas (Table 3). But in 1974 and 1975, lake densities exceeded river densities because green and blue-green algae were more common in the lake. The lake algae were more evenly distributed among the

TABLE 11. MEAN ANNUAL PHYTOPLANKTON ABUNDANCE[*] BY MAJOR CLASS
(no./ml)

Class	17	9	18	12	14
Bacillariophyceae					
1973[¶]	4373	7773	4543	4688	5921
1974[¶]	2568	1993	2486	2048	4220
1975[†]	3878	7471	5440	3946	5412
Three-year Mean	3606	5746	4156	3561	5184
Chloride Prediction[‡]				4280	4365
Cyanophyceae					
1973	826	552	784	1007	863
1974	1254	36	1164	3861	1574
1975	9128	251	8755	4682	13965
Three-year Mean	3736	279	3568	3184	5467
Chloride Prediction				3675	3748
Chlorophyceae					
1973	1455	932	1394	1454	1460
1974	2391	467	2278	836	1975
1975	1495	1310	1660	1089	1423
Three-year Mean	1780	903	1777	1126	1619
Chloride Prediction				1831	1867
Euglenophyceae					
1973	25	104	76	80	63
1974	38	33	32	32	48
1975	86	275	169	44	149
Three-year Mean	50	138	92	52	87
Chloride Prediction				95	97

[*] Afternoon data only.

[¶] Mean of five samples, one station on six dates.

[†] Mean of five samples, one station on five dates.

[‡] Chloride prediction is the expected concentration based on mean chloride concentrations.

(continued)

TABLE 11 (continued).

Class	17	9	18	12	14
Dinophyceae					
1973	0	0	0	0	0
1974	12	0	5	0	5
1975	34	0	31	6	23
Three-year Mean	15	0	12	2	9
Chloride Prediction				13	13
Cryptophyceae					
1973	11	2	7	21	13
1974	149	13	140	3	70
1975	133	29	126	0	42
Three-year Mean	98	14	91	8	42
Chloride Prediction				92	92
Chrysophyceae					
1973	0	6	2	0	8
				2	2
Chlorobacteriae					
1973	0	0	0	0	19
				0	0
Total					
1973	6691	7205	6807	7248	7702
1974	7375	2544	5107	6749	7894
1975	14755	4330	16184	9769	21015
Three-year Mean	9607	7895	9366	7922	14844
Chloride Prediction				9647	9840

TABLE 12. VERTICAL DISTRIBUTION (PERCENT OF TOTAL AND TOTAL NUMBER AT EACH DEPTH) IN THE COOLING SYSTEM (AFTERNOON DATA ONLY) IN 1973 AT STATIONS OVER THREE METERS DEEP

Depth and Class	STATION 17	 9	 12	 8
Bacillariophyceae				
0	73.2	77.3	71.6	65.4
2	70.1	78.3	72.7	66.0
3	71.7	81.3	70.3	71.0
4	77.1	77.9	70.8	70.2
6	72.8	79.6	73.3	73.3
Chlorophyceae				
0	16.5	11.2	17.0	20.7
2	20.4	12.9	17.3	17.2
3	19.6	12.3	14.4	16.0
4	17.0	12.7	17.0	16.3
6	16.0	12.5	16.7	14.9
Cyanophyceae				
0	9.7	8.7	6.8	9.2
2	8.4	5.7	7.3	11.0
3	7.5	3.4	12.8	8.5
4	5.6	5.6	9.4	10.0
6	10.4	5.6	8.5	8.5
Total Abundance (no./ml)				
0	7123.2	6859.3	8628.5	8729.3
2	7388.2	7769.8	8026.1	8080.6
3	6612.5	9628.9	8130.3	8760.1
4	7704.3	8335.7	8178.0	8307.0
6	7951.2	7726.4	7489.5	8587.6

three important classes than the diatom-dominated river algae. Year to year variations in river discharge contributed to the annual variation of entrained algae. In 1975 the river contributed only one fourth of the cooling water compared to about half in the preceeding years. Because of low summer discharges, the river contributed relatively little to the dynamics of green and blue-green algae.

Total algal densities consistantly increased as water passed from the upper to the lower discharge canal from station 12 to station 14 during each of the three years (Table 11). Algal abundances in the plume were measured only in 1973 when the mean of all sampling dates and time periods indicated that the algae maintained greater densities in the mixing plume than expected from dilution; particularly green and blue-green algae (Table 13).

The mean density of most algal classes consistantly increased as water passed from the upper to the lower end of the discharge canal. The major exception, the blue-green algae probably vacillated because they were variable in the source water. In 1975, an extraordinary bloom of blue-green algae on one date generated an atypically high mean algal increase in the discharge canal; otherwise, the increments were only 10 to 20 percent. The variability of blue-green algae also materialized in the 1973 comparisons of morning, afternoon and evening samples (Table 14). Although the daily mean algal concentrations remained greater in the plume than predicted by dilution, this observation was inconsistant for different times of the day. Mean afternoon densities declined more than predicted, while mean morning and evening densities remained higher than predicted. This variation was caused mostly by variation in blue-green algal response and secondarily by green algal response. These two classes varied up to 35 percent from one time period to another. In contrast, diatom concentrations were relatively similar at all three time periods and exhibited consistent changes with passage through the cooling system. Although the differences in concentration from one time period to another could be as much as 35 percent, there was no indication that entrainment was consistently different at specific times of the day.

The changes in mean annual density, volume and individual volume, of the important species, exhibited no consistant trends from year to year which were related to the length of power plant operation (Table 15). Although the mean annual concentration of a few species varied by up to 2 orders of magnitude, their variation appeared to be independent of time. Most of the common species remained consistantly abundant during the three-year study; their mean annual concentrations varied only by 2 to 5 times. The mean annual size of the algal units (cells, filaments, or colonies) varied independently of numerical abundance as did the mean annual volumes of each species.

The response of dominant species to cooling water passage in 1973 was highly variable; some species seemed to decrease more than predicted by chloride concentrations (Anacystis incerta, Scenedesmus quadricaudus, Cyclotella menegheniana), another species seemed to increase (Ulothrix subtillissima) but most species behaved generally without notable trend. The mean size of classes and the most important species varied without trend. As expected with taxa comprising small samples, the rare classes changed erratically in mean size and abundance. The species composition may have shifted slightly as plankton drifted through the cooling system, but the impact, if it were real and not a product of patchy

TABLE 13. MEAN ANNUAL ALGAL DENSITIES, VOLUME, AND MEAN INDIVIDUAL VOLUMES FOR CLASSES AND DOMINANT SPECIES IN THE COOLING SYSTEM DURING 1973*
(no./ml; μ^3/ml; μ^3/individual)

Taxa	STATIONS 17	9	18	12	8	14	15	16
Cyanophyceae								
Numbers	1895	1612	1787	1901	2438	2184	2261	2587
Volume	583596	416676	502900	512722	638273	651822	732119	802987
Mean Size	308	258	281	270	262	297	324	310
Aphanizomenon gracile								
Numbers	105	20	70	80	50	53	58	61
Volume	182650	39713	123047	134727	90752	95232	125310	130840
Mean Size	1738	1956	1748	1688	1833	1790	2146	2163
Anacystis incerta								
Numbers	94	30	81	151	106	60	5	0
Volume	28617	7796	24703	40184	29565	17691	1443	0
Mean Size	306	263	307	267	278	293	267	--
Chlorophyceae								
Numbers	2202	208	2164	2130	2233	2342	2708	2213
Volume	1702333	1304603	1576254	1472888	1525274	1601120	2262384	1876212
Mean Size	733	627	729	691	683	684	835	848
Scenedesmus quadricauda								
Numbers	41	50	44	48	38	96	37	19
Volume	5804	8300	6395	7131	5316	13321	7378	3642
Mean Size	142	166	147	147	141	139	196	191
Ulothrix subtillissima								
Numbers	241	66	187	130	212	128	557	579
Volume	231984	65931	178928	125383	195620	118282	560344	582092
Mean Size	965	1007	959	962	923	926	1006	1006

* Class data is averaged for all periods, species data is averaged on afternoons only.

(continued)

TABLE 13 (continued)

Taxa	STATIONS							
	17	9	18	12	8	14	15	16
Bacillariophyceae								
Numbers	4567	5171	4620	4855	4790	5204	4419	4234
Volume	16781518	12766022	14003792	14898492	13304654	15221607	14639830	15453619
Mean Size	3674	2468	3031	3068	2777	2925	3312	3649
Coscinodiscus radiatus								
Numbers	808	146	611	634	544	681	534	691
Volume	6344544	1045601	4817834	4923665	4221031	5344670	4292718	5478816
Mean Size	7853	7152	7883	7764	7765	7855	8034	7919
Cyclotella meneghiniana								
Numbers	966	2197	1308	1176	1506	1504	894	566
Volume	1122787	2458304	1439562	1200589	1511954	1562975	729339	457379
Mean Size	1163	1119	1101	1021	1004	1039	816	808
Euglenophyceae								
Numbers	78	104	98	86	111	84	102	77
Volume	47786	58153	54003	39849	64777	49762	68325	57753
Mean Size	615	562	549	462	585	586	670	747
Cryptophyceae								
Numbers	11	7	11	9	23	16	20	9
Volume	9348	6244	9041	7838	19560	13472	17904	8055
Mean Size	858	855	861	852	858	869	873	857
Chrysophyseae								
Numbers	1	2	1	1	3	3	0	0
Volume	4	2291	573	758	2747	3304	0	0
Mean Size	10	1041	1146	842	858	1032	—	--

(continued)

TABLE 13 (continued)

Taxa	STATIONS 17	9	18	12	8	14	15	16
Dinophyceae								
Numbers	0	1	1	1	1	2	0	0
Volume	0	5019	1832	552	3612	3863	0	2796
Mean Size	--	3585	3664	552	3612	2033	--	3495
Chlorobacteriae								
Numbers	0	0	0	0	2	6	0	0
Volume	708	0	0	0	114	9395	0	0
Mean Size	1770	--	--	--	63	1468	--	--

TABLE 14. MEAN ANNUAL ALGAL DENSITY BY CLASS AT DIFFERENT TIMES OF THE DAY IN 1973

(no./ml)

Station and Time	CLASS						
	A*	B*	C*	D*	E*	F*	Total
17 morn.	902	1350	5126	134	0	11	7523
aft.	827	1456	4373	25	0	11	6692
eve.	1098	999	4130	73	0	11	6311
9 morn.	772	1222	4667	98	4	5	6768
aft.	552	932	5611	105	0	2	7202
eve.	1010	1240	5251	108	0	16	7625
18 morn.	842	1300	4968	109	2	10	7221
aft.	785	1394	4543	77	0	8	6807
eve.	1044	1073	4295	112	0	15	6489
12 morn.	897	1253	4938	321	0	6	7415
aft.	1001	1454	4688	80	3	22	14663
eve.	984	1000	4940	58	0	0	6982
8 morn.	1336	1363	4981	119	0	11	7810
aft.	1065	1648	4832	102	3	41	7691
eve.	1161	931	4559	112	0	16	6779
14 morn.	1162	1366	5026	111	6	11	7682
aft.	864	1460	5275	64	0	13	7676
eve.	1122	1193	5311	80	0	22	7728
15¶ morn.	1131	1466	5068	134	0	33	7832
eve.	1210	1479	3799	85	0	23	6496
16¶ morn.	1318	1237	4694	87	2	17	7355
eve.	1393	1041	3983	77	0	8	6502

* A = Cyanophyceae
B = Chlorophyceae
C = Bacillariophyceae
D = Euglenophyceae
E = Dinophyceae
F = Cryptophyceae

¶ Afternoon samples were incompletely sampled during summer and were left out of the comparison.

TABLE 15. MEAN ABUNDANCE AND SIZE OF IMPORTANT PHYTOPLANKTON SPECIES SAMPLED IN THE UPPER DISCHARGE CANAL AT STATION 12

Species	Numbers/ml			Volumes (μ^3/ml)			Mean Volume/ml		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
Bacillariophyceae (Diatoms)									
Cocconeis placentula	30	15	11	15781	5626	9237	523	368	840
Coscinodiscus radiatus	633	332	438	4923665	2179994	6887550	7778	6562	15721
Cyclotella meneghiniana	1175	222	288	1200589	383329	438699	1021	1725	1519
Melosira granulata	256	4	64	704159	4922	81721	2742	1158	1273
Navicula cryptocephala	67	20	90	22792	12009	49162	337	586	545
Nitzschia acicularis	62	34	68	36298	23187	25341	577	680	368
Stephanodiscus astrae	241	47	139	655837	138680	318039	2711	2952	2286
Stephanodiscus niagarae	272	41	9	3527071	412548	130142	12948	9846	14146
Tabellaria fenestrata	44	18	25	80497	385346	734764	2519	4328	151426
Chlorophyceae (Green algae)									
Actinastrum hantzxchii	21	25	37	1082	1718	5422	49	67	145
Binuclearia eriensis	39	0	45	441043	0	62147	11109	—	1172
Dictyosphaerium pulchellum	60	74	53	21662	2520	56707	360	34	1056
Mougeotia elegantula	18	75	1	127439	635597	1744	6889	8374	1163
Scenedesmus quadricauda	117	97	150	28902	16761	40904	246	172	273
Ooeystis parva	16	23	20	3646	6840	15455	225	296	765
Ulothrix subtillissima	130	142	1	125383	115812	3416	962	813	2277
Cyanophycea (Blue-greens)									
Anacystis incerta	150	23	62	40185	12431	16407	267	52	262
Aphanizomenon gracile	79	179	503	134728	244633	201701	1688	1361	401
Euglenophyceae									
Trachelomonas volvocina	59	0	25	11515	0	8569	194	--	335

*Afternoon data only.

distribution, did not seem to have more than a transitory influence on the lake composition.

Although some compositional changes may have occurred among the entrained phytoplankton, diversity measures indicated that a stable structure was maintained throughout the cooling system (Tables 16, 17). Generic diversity and species diversity were similar for the same data collected in 1973. Both diversity measures indicated that no important, consistent changes occurred in the cooling system or the plume during cooling water passage. Generic diversity was stable over the three years in the lake at station 17 but river diversity decreased in 1975 and seemed to influence the diversity in the discharge canal as a consequence of mixing. Passage through the cooling system had no measured affect on algal diversity.

In summary, the affects of entrainment on phytoplankton were subtle if real at all. Variability in the spatial distribution of algae precluded consistant statistical differentiation of abundances in the cooling system. But, overall, the mean effects integrated over the annual cycle were at most minor effects. Mean annual algal concentrations probably increased slightly in the cooling waters discharged to the lake. Although responses were inconsistant, the increase seemed to be caused by growth of blue-green and green algae.

PERIPHYTON

Periphyton was rare in the study area because appropriate substrate was scarce, but periphyton accumulation on artificial substrates was used to assess the integrated effects of water quality on productivity at a fixed site within the cooling system. Periphytic growth was throught to be less likely than entrained phytoplankton to reflect previous impacts from mechanical damage, thermal "shock", or chemical "shock" caused by transport through the pumps and condenser.

Because periphyton samples are particularly vulnerable to weather, the variation among replicates was high in some instances so the effects of the cooling system were not always clear (Fig. 10; C4). Of the four tests conducted, periphyton accumulation rates were clearly affected in the upper discharge canal only in mid-summer when water temperatures were highest. Spring accumulations may have been influenced also but replicate variation interfered with the determination. The least differences occurred among the sampling stations in winter when the absolute temperatures were lowest.

During summer and spring, greater productivity occurred at the mouth of the discharge canal than in the upper part of the discharge canal where no differences were observed in winter or late summer samples. Neither temperature nor light penetration (suspended solids) seemed to be different enough in the upper and lower discharge canal to explain the difference in periphyton accumulation rates. If chlorine were responsible for differences, its impact was inconsistent for the different sampling dates. The thermal regimes were similar for spring and late summer but the affects appeared to be different.

TABLE 16. DIVERSITY AND EQUITABILITY CALCULATED FROM DENSITY AND BIOMASS DATA COLLECTED FROM THE COOLING SYSTEM

		STATION							
Diversity Date-Period		17	9	18	12	8	14	15	16
Morning 11/09/72	Numbers	1.18*	1.21	1.21	1.06	1.03	1.09	1.25	1.17
	Biomass	0.83	1.14	1.14	1.11	1.08	1.17	0.92	0.91
Evening 11/09/72	Numbers	1.11	0.96	0.96	1.07	0.97	1.06	1.12	1.14
	Biomass	0.88	0.96	0.96	1.07	1.00	1.13	0.73	0.81
Afternoon 11/10/72	Numbers	1.23	1.13	1.13	1.03	1.08	1.25	1.16	1.15
	Biomass	0.93	1.02	1.02	1.07	1.13	0.96	0.89	0.73
Afternoon 01/24/73	Numbers	1.49	1.46	1.55	1.49	1.39	1.34	1.43	1.33
	Biomass	1.31	1.40	1.47	1.41	1.37	1.34	1.26	1.09
Afternoon 04/05/73	Numbers	1.34	1.26	1.39	1.34	1.28	1.42	1.32	1.41
	Biomass	1.07	1.22	1.35	1.34	1.28	1.41	1.30	1.33
Afternoon 06/12/73	Numbers	1.35	1.37	1.43	1.40	1.42	1.44	1.28	1.14
	Biomass	1.17	1.26	1.26	1.19	1.23	1.25	1.08	0.96
Afternoon 08/09/73	Numbers	1.52	1.33	1.55	1.48	1.52	1.38	--	--
	Biomass	1.14	1.08	1.19	1.01	1.12	0.95	--	--
Afternoon 09/29/73	Numbers	1.38	--	1.38	1.35	1.36	1.32	--	--
	Biomass	0.94	--	0.99	1.13	1.20	1.06	--	--

*The mean of five samples.

(continued)

TABLE 16 (continued)

Equitability Date-Period		STATION							
		17	9	18	12	8	14	15	16
Morning 11/09/72	Numbers	0.70*	0.76	0.76	0.67	0.65	0.68	0.74	0.70
	Biomass	0.49	0.73	0.73	0.70	0.68	0.73	0.55	0.54
Evening 11/09/72	Numbers	0.72	0.70	0.70	0.65	0.66	0.75	0.70	0.68
	Biomass	0.54	0.65	0.65	0.68	0.66	0.69	0.43	0.49
Afternoon 11/10/72	Numbers	0.72	0.70	0.70	0.65	0.66	0.75	0.70	0.68
	Biomass	0.54	0.63	0.63	0.67	0.69	0.57	0.53	0.43
Afternoon 01/24/73	Numbers	0.88	0.87	0.85	0.88	0.87	0.81	0.84	0.81
	Biomass	0.78	0.84	0.80	0.84	0.85	0.81	0.74	0.66
Afternoon 04/05/73	Numbers	0.80	1.34	0.77	0.81	0.76	0.82	0.79	0.84
	Biomass	0.64	0.75	0.75	0.81	0.76	0.82	0.78	0.79
Afternoon 06/12/73	Numbers	0.78	0.78	0.76	0.82	0.83	0.82	0.77	0.67
	Biomass	0.68	0.73	0.67	0.70	0.72	0.71	0.65	0.57
Afternoon 08/09/73	Numbers	0.82	0.73	0.77	0.79	0.81	0.76	--	--
	Biomass	0.61	0.60	0.59	0.54	0.59	0.52	--	--
Afternoon 09/29/73	Numbers	0.75	--	0.72	0.77	0.75	0.75	--	--
	Biomass	0.51	--	0.52	0.65	0.66	0.60	--	--

*The mean of five samples.

TABLE 17. MEAN ANNUAL PHYTOPLANKTONIC GENERIC DIVERSITY AND EQUITABILITY IN THE COOLING SYSTEM FROM 1973 to 1975[*]

	STATION				
	17	9	18	12	14
Diversity					
Numbers					
1973[¶]	1.12	1.00	1.10	1.07	1.08
1974[¶]	1.07	.79	1.05	.96	1.11
1975[†]	1.13	.71	.88	.95	.87
Biomass					
1973	0.93	0.98	1.02	0.98	0.97
Equitability					
Numbers					
1973	0.76	0.71	0.72	0.74	0.74
1974	0.72	0.49	0.62	0.69	0.75
1975	0.60	0.52	0.57	0.70	0.60
Biomass					
1973	0.63	0.69	0.67	0.69	0.67

---

[*] Afternoon data only.

[¶] Mean of five replicates, one station on six dates in 1973 and 74.

[†] Mean of five replicates, one station on five dates in 1975.

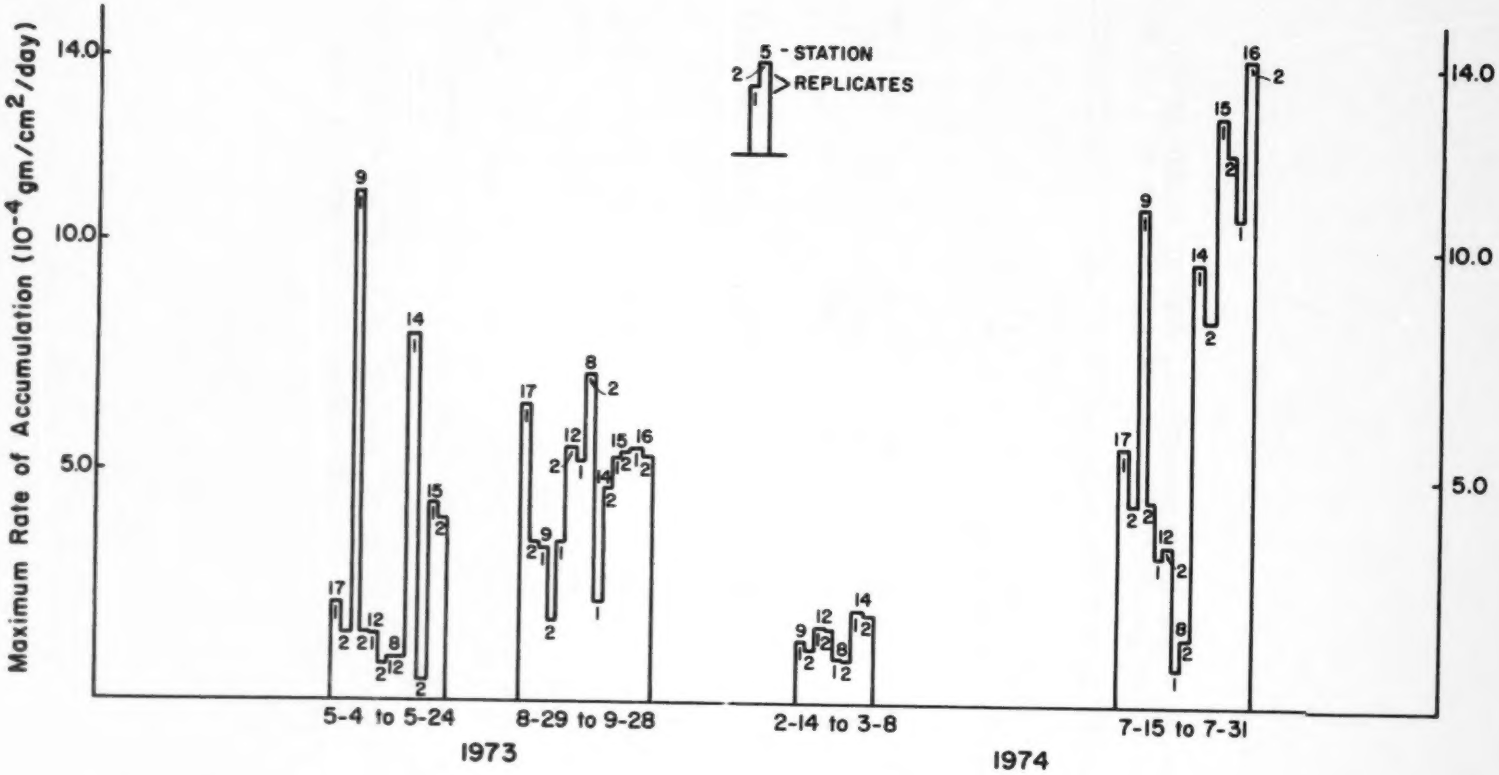


Figure 10. Accumulation of periphyton during four seasons in the cooling system at the Monroe Power Plant.

COMMUNITY METABOLISM

Mean annual gross primary productivity in the upper discharge canal usually was less than expected from the simple mixing of river and lake waters. Water in the upper discharge canal usually was less productive than lake water and similar to the river water. Mean afternoon productivities were similar to morning productivities. Evening productivity averaged close to 0 as expected for the dark hours. At least three possibilities could have been totally or partly responsible for the inhibition of productivity in the upper discharge canal; some inhibitor(s) associated with the river water, temperature elevation or the mechanical effects from condenser passage. No chlorination occurred in the afternoon so depressions at that time had to be caused by some other alternation(s).

Primary productivity was much more intense during the warm months (Table 18; B21) than during the cool months so the average inhibition mostly reflected summer conditions. There was little obvious relationship between the absolute temperature and the intensity of the measured response on any particular date, but, at higher ambient temperatures, the productivity in the discharge canal appeared to be inhibited more by the passage.

Productivity appeared to recover as water passed from the discharge canal back into the lake (Table 18). By the time discharged water reached mid-plume at station 15, mean productivity usually exceeded that at the lake source (station 17). This elevated productivity (mean of 50%) persisted to the plume edge where temperatures were only slightly elevated above ambient.

Mean annual respiration in the upper discharge canal usually was slightly greater than respiration in the source waters (Table 19; B22). The increases associated with condenser passage occurred at all times of the day regardless of the chlorination schedule. Either temperature elevation or mechanical effect may have been responsible. After community respiration accelerated, it tended to return to source-water respiration rates as the cooling water mixed back into the lake, but remained elevated above the level in the source waters even at the plume edge where temperatures were nearly ambient.

The mean annual ratios of gross primary productivity and community respiration in the upper discharge canal usually were less than that projected for the mix of source waters (Table 20). The ratios remained relatively low throughout the discharge flow then returned to levels similar to ratios observed in the lake source water. No consistent changes in the metabolic "balance" of the plume waters occurred because of the cooling water passage.

ZOOPLANKTON

Zooplankton abundance varied from nearly negligible quantities of copepods, cladocerans and rotifers in winter to greatest concentrations in late summer and early fall (Table 21; 22; B23; Fig. 11). Biomass varied over the year more than density because small rotifers were relatively numerous in winter. The three most abundant species during the study were Bosmina sp., Cyclops vernalis and Daphnia retrocurva. These species were most abundant from June through September; and nearly all zooplankton entrainment occurred between April and November.

TABLE 18. MEAN GROSS PRIMARY PRODUCTIVITY IN THE COOLING SYSTEM FOR COLD AND WARM MONTHS OF 1973-75
(mg O_2/liter/hour)

Period Year-Season	STATIONS 17	9	18	12	8	14	15	16
Morning								
1973-cool*	0.03[†]	0.06	0.06	0.03	0.00	0.03	0.05	0.01
-warm[¶]	0.76	0.39	0.66	0.34	0.36	0.42	0.62	0.79
1974-cool	0.04	0.06	0.04	0.04	0.01	0.03	0.05	0.00
-warm	0.52	0.22	0.49	0.33	0.48	0.50	0.61	0.73
1975-cool	0.08	-0.02	0.04	0.08	0.07	0.02	-0.05	0.12
-warm	0.54	0.56	0.62	0.58	0.54	0.74	0.64	0.64
Grand cool mean	0.05	0.03	0.05	0.05	0.03	0.03	0.02	0.04
Grand warm mean	0.61	0.39	0.59	0.47	0.46	0.55	0.62	0.72
3 year grand mean	0.33	0.21	0.32	0.24	0.24	0.29	0.32	0.44
Afternoon								
1973-cool	-0.04	0.01	0.00	0.01	0.03	0.05	0.07	0.00
-warm	0.26	0.13	0.22	0.21	0.12	0.16	0.31	0.30
1974-cool	0.04	-0.01	0.00	0.04	-0.02	0.00	0.00	0.01
-warm	0.43	0.33	0.42	0.41	0.40	0.43	0.58	0.43
1975-cool	Data not gathered -- assumed to be zero based on 1973 and 1974							
-warm	0.70	0.34	0.62	0.33	0.41	0.41	0.95	0.88
Grand cool mean	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.00
Grand warm mean	0.46	0.27	0.42	0.32	0.31	0.33	0.61	0.56
3 year grand mean	0.23	0.13	0.21	0.18	0.16	0.18	0.22	0.27

*Cool season extended from November through April with temperatures generally less than 10°C.

[¶] Warm season extended from May through October with temperatures generally above 15°C.

[†] The mean of three replicates.

(continued)

TABLE 10 (continued)

Period Year-Season	STATIONS 17	9	18	12	8	14	15	16
Evening								
1973-cool[*]	0.02[†]	-0.02	-0.01	0.00	0.00	0.00	0.01	0.00
-warm[‡]	0.02	0.02	0.04	-0.03	0.00	0.01	-0.06	-0.01
1974-cool	-0.05	0.01	0.02	-0.01	0.03	0.01	-0.01	-0.03
-warm	-0.01	0.02	-0.01	-0.02	-0.08	-0.01	0.00	-0.01
1975-cool	-0.04	-0.04	-0.04	-0.03	-0.02	-0.04	0.00	-0.01
-warm	0.04	-0.04	0.03	-0.05	-0.10	0.07	0.04	0.03
Grand cool mean	-0.02	-0.02	-0.01	-0.01	0.00	-0.01	0.00	-0.01
Grand warm mean	0.02	0.00	0.02	-0.03	-0.06	0.02	-0.01	0.00
3 year grand mean	0.00	-0.01	0.00	-0.02	-0.03	0.00	0.00	0.00
OVERALL GRAND MEAN	0.22	0.13	0.21	0.14	0.15	0.18	0.30	0.30

[*] Cool season extended from November through April with temperatures generally less than 10°C.

[‡] Warm season extended from May through October with temperatures generally above 15°C.

[†] The mean of three replicates.

TABLE 19. MEAN RESPIRATION RATE IN THE COOLING SYSTEM FOR COLD AND WARM MONTHS OF 1973-75

(mg O_2/liter/hour)

Period Year-Season	STATIONS 17	 9	 18	 12	 8	 14	 15	 16
Morning								
1973-cool*	0.00†	0.05	0.04	0.01	0.02	0.05	0.02	-0.01
-warm¶	0.08	0.07	0.08	0.05	0.08	0.08	0.09	0.10
1974-cool	0.04	0.03	0.00	0.05	0.03	0.03	0.02	0.00
-warm	0.10	0.05	0.09	0.08	0.08	0.09	0.09	0.09
1975-cool	0.00	0.06	0.03	0.10	0.12	0.06	0.02	0.00
-warm	0.10	0.06	0.06	0.14	0.13	0.10	0.03	0.05
Grand cool mean	0.01	0.05	0.02	0.05	0.06	0.05	0.02	0.00
Grand warm mean	0.09	0.06	0.08	0.09	0.10	0.09	0.07	0.09
3 year grand mean	0.05	0.05	0.05	0.07	0.08	0.06	0.05	0.05
Afternoon								
1973-cool	0.10	0.05	0.01	0.07	0.11	0.12	-0.02	0.00
-warm	0.09	0.16	0.11	0.12	0.05	0.08	0.11	0.08
1974-cool	0.02	-0.01	-0.02	0.05	0.03	0.02	-0.02	0.00
-warm	0.03	0.04	0.04	0.13	0.14	0.13	0.03	0.12
1975-cool	data missing							
-warm	0.09	-0.02	0.08	0.10	0.13	0.11	0.12	0.17
Grand cool mean	0.06	0.02	0.00	0.06	0.07	0.07	-0.02	0.00
Grand warm mean	0.07	0.06	0.08	0.12	0.11	0.11	0.09	0.12
3 year grand mean	0.06	0.04	0.04	0.09	0.09	0.09	0.04	0.06

[*] Cool season extended from November through April with temperatures generally less than 10°C.

[¶] Warm season extended from May through October with temperatures generally above 15°C.

[†] The mean of three replicates.

(continued)

TABLE 19 (continued)

Period Year-Season	STATIONS 17	9	18	12	8	14	15	16
Evening								
1973-cool[*]	-0.02[†]	-0.05	-0.05	0.03	0.03	0.06	0.02	0.00
-warm[¶]	0.03	0.09	0.05	0.09	0.07	0.04	0.04	-0.04
1974-cool	-0.01	-0.04	-0.03	0.05	0.05	0.09	-0.02	-0.04
-warm	0.06	0.04	0.06	0.07	0.11	0.05	0.09	0.04
1975-cool	-0.06	0.00	-0.04	0.08	0.06	0.05	0.01	0.04
-warm	0.02	0.05	0.01	0.09	-0.05	0.09	0.08	0.09
Grand cool mean	-0.03	-0.03	-0.04	0.05	0.05	0.07	0.00	0.00
Grand warm mean	0.04	0.06	0.04	0.08	0.04	0.06	0.07	0.03
3 year grand mean	0.01	0.02	0.00	0.07	0.04	0.06	0.04	0.01
OVERALL GRAND MEAN	0.04	0.04	0.04	0.08	0.07	0.07	0.05	0.06

[*] Cool season extended from November through April with temperatures generally less than 10°C.

[¶] Warm season extended from May through October with temperatures generally above 15°C.

[†] The mean of three replicates.

TABLE 20. P/R RATIOS IN THE COOLING SYSTEM FOR WARM AND COLD MONTHS OF 1973-75

Period Year-Season	STATIONS 17	 9	 18	 12	 8	 14	 15	 16
Morning								
1973-cool[*]	∞[†]	1.20	1.50	3.00	0.00	0.60	2.50	-1.00
-warm[¶]	9.50[‡]	5.57	8.25	6.80	4.50	5.25	6.89	7.90
1974-cool	1.00	2.00	∞	0.80	0.33	1.00	2.50	0.00
-warm	5.20	4.40	5.44	4.12	6.00	5.56	6.78	8.11
1975-cool	∞	-0.33	1.33	0.80	0.58	0.33	-2.50	∞
-warm	5.40	9.33	10.33	4.14	4.15	7.40	21.33	8.00
Grand cool mean	5.00	0.60	2.50	1.00	0.50	0.60	1.00	∞
Grand warm mean	6.78	6.50	7.38	4.67	4.60	6.11	8.86	8.00
3 year grand mean	6.66	4.20	6.40	3.43	3.00	4.83	6.40	8.80

[*] Cool season extended from November through April with temperatures generally less than 10°C.

[¶] Warm season extended from May through October with temperatures generally above 15°C.

[†] When respiration equals zero; and productivity is positive, the calculated ratio is 20. These ratios were left out of grand mean calculations.

[‡] The mean of three replicates.

(continued)

TABLE 20 (continued)

Period Year-Season	STATIONS 17	 9	 18	 12	 8	 14	 15	 16
Afternoon								
1973-cool[*]	-0.40[†]	0.20	∞	0.14	0.27	0.42	-3.50	0.00
-warm[¶]	2.89[‡]	0.81	2.00	1.75	2.40	2.00	2.82	3.75
1974-cool	2.00	1.00	0.00	0.80	-0.67	0.00	0.00	∞
-warm	14.33	8.25	10.50	3.15	2.86	3.31	19.33	3.58
1975-cool	--	--	--	--	--	--	--	--
-warm	7.78	-17.00	7.75	3.30	3.15	9.09	7.92	5.18
Grand cool mean	0.00	0.00	0.00	0.50	0.00	0.29	-2.00	0.00
Grand warm mean		4.50	6.25	2.67	2.82	3.00	6.78	4.50
3 year grand mean	3.83	4.00	3.50	1.85	1.78	2.00	5.50	4.50
OVERALL GRAND MEAN	5.50	3.25	5.25	1.75	2.14	2.57	6.00	5.00

[*] Cool season extended from November through April with temperatures generally less than 10°C.

[¶] Warm season extended from May through October with temperatures generally above 15°C.

[†] When respiration equals zero; and productivity is positive, the calculated ratio is 20. These ratios were left out of grand mean calculations.

[‡] The mean of three replicates.

TABLE 21. MEAN ANNUAL DENSITY OF ZOOPLANKTON IN THE COOLING SYSTEM
(numbers/liter)

Taxa	STATIONS 17	 9	 18	 12	 8
1972-73					
Rotifera	76.3 (56.1)*	43.0 (43.3)	65.7 (51.6)	45.0 (51.1)	60.4 (54.4)
Cladocera	28.8 (16.5)	22.3 (22.3)	27.0 (13.2)	11.5 (11.5)	14.5 (5.2)
Daphnia sp.	13.6 (6.2)	3.2 (1.2)	10.3 (5.1)	3.6 (2.5)	5.6 (3.3)
Bosmina sp.	10.9 (5.4)	5.0 (8.5)	9.1 (7.2)	6.2 (5.4)	7.2 (4.4)
Adult Copepoda	61.6 (48.1)	31.2 (5.0)	54.5 (31.8)	44.0 (47.5)	52.6 (30.8)
Adult *C. vernalis*	57.7 (36.7)	27.0 (4.8)	52.3 (27.4)	43.5 (39.2)	40.9 (28.7)
Nauplii	26.4 (20.7)	18.3 (14.0)	24.3 (16.7)	16.1 (13.5)	25.6 (22.1)
Total Copepoda	88.0 (68.8)	49.5 (19.0)	78.8 (48.5)	60.1 (60.7)	78.2 (52.9)
Total	193.1 (141.4)	114.8 (84.6)	171.5 (113.3)	116.6 (123.3)	153.1 (112.5)
1973-74					
Rotifera	162.1 (181.2)	107.7 (85.0)	155.1 (173.3)	103.7 (104.6)	113.1 (78.2)
Cladocera	31.7 (30.2)	11.9 (13.3)	28.4 (27.3)	17.6 (11.0)	17.2 (5.8)
Daphnia sp.	9.0 (15.8)	.5 (0.0)	7.2 (6.7)	3.0 (0.0)	1.8 (1.7)
Bosmina sp.	18.7 (12.7)	7.4 (5.8)	16.2 (11.7)	12.1 (9.4)	12.6 (2.7)
Adult Copepoda	6.1 (8.5)	3.6 (.8)	5.2 (5.8)	4.9 (5.0)	6.2 (5.0)
Adult *C. vernalis*	4.2 (5.8)	2.7 (.8)	3.6 (5.6)	3.5 (5.0)	3.8 (3.3)
Nauplii	54.9 (50.2)	22.3 (20.2)	48.4 (46.6)	39.2 (26.0)	42.3 (39.8)
Total Copepoda	61.0 (58.7)	25.9 (20.2)	53.6 (52.4)	44.1 (31.0)	48.5 (44.8)
Total	254.8 (270.1)	145.5 (118.5)	237.1 (253.0)	165.4 (146.6)	178.8 (128.8)
1975					
Rotifera	145.2 (183.0)	47.3 (35.5)	109.0 (129.2)	70.9 (77.1)	69.6 (71.2)
Cladocera	17.6 (11.0)	5.3 (2.0)	16.5 (10.0)	8.6 (4.1)	15.3 (2.6)
Daphnia sp.	6.6 (2.0)	2.4 (0.0)	6.1 (1.9)	1.4 (3.0)	2.9 (1.0)
Bosmina sp.	2.4 (4.0)	.8 (1.0)	2.0 (3.7)	2.8 (.12)	1.6 (1.0)
Adult Copepoda	2.8 (1.9)	1.1 (.2)	2.1 (1.4)	2.8 (4.1)	3.3 (3.5)
Adult *C. vernalis*	1.5 (1.1)	1.0 (.1)	.9 (1.0)	1.8 (4.0)	2.3 (3.5)
Nauplii	15.6 (19.4)	11.5 (2.5)	14.1 (16.3)	15.8 (8.4)	17.6 (16.6)
Total Copepoda	18.4 (21.3)	12.6 (2.5)	16.2 (17.7)	18.6 (12.5)	20.9 (20.1)
Total	181.2 (2.5.3)	65.2 (40.0)	141.7 (156.9)	98.1 (93.7)	105.8 (93.3)

* Number in parentheses is the mean number at the surface

TABLE 22. MEAN ANNUAL BIOMASS OF ZOOPLANKTON IN THE COOLING SYSTEM
(μg/liter)

Taxa	STATIONS 17	9	18	12	8
1972-73					
Rotifera	8.6 (7.1)*	7.0 (7.7)	7.1 (5.3)	5.4 (6.6)	9.2 (9.2)
Cladocera	175.7 (79.3)	49.8 (14.0)	138.7 (61.5)	136.1 (56.0)	98.2 (24.6)
Daphnia sp.	134.8 (74.6)	44.9 (6.9)	119.1 (56.1)	38.7 (41.5)	54.9 (19.0)
Bosmina sp.	17.1 (28.9)	4.2 (7.0)	10.2 (4.7)	5.0 (3.6)	4.3 (4.6)
Adult Copepoda	219.7 (148.0)	133.0 (47.7)	209.5 (107.4)	171.9 (170.8)	134.1 (103.2)
Adult *C. vernalis*	153.8 (109.9)	107.1 (47.4)	170.2 (89.4)	148.1 (138.2)	111.0 (93.3)
Nauplii	4.4 (3.6)	3.9 (2.7)	2.6 (1.9)	1.7 (1.4)	2.3 (1.9)
Total Copepoda	224.1 (151.6)	136.9 (50.4)	212.1 (109.3)	173.6 (172.2)	136.4 (105.1)
Total	408.4 (238.0)	193.7 (72.1)	357.9 (176.1)	315.1 (234.8)	243.8 (138.9)
1973-74					
Rotifera	14.3 (12.8)	16.4 (11.3)	15.0 (12.6)	11.8 (12.9)	19.4 (8.7)
Cladocera	94.8 (182.8)	15.0 (4.1)	77.3 (145.8)	24.7 (4.7)	19.6 (10.6)
Daphnia sp.	83.4 (175.5)	8.5 (0.0)	67.8 (138.8)	19.0 (0.0)	11.1 (5.6)
Bosmina sp.	12.3 (6.9)	4.1 (1.0)	10.7 (6.1)	5.2 (4.1)	7.9 (3.6)
Adult Copepoda	26.5 (45.0)	9.4 (1.6)	22.9 (36.8)	14.5 (12.2)	22.0 (18.1)
Adult *C. vernalis*	15.4 (18.7)	7.2 (1.6)	13.8 (14.0)	11.3 (12.2)	11.8 (11.1)
Nauplii	6.2 (4.5)	2.4 (2.0)	5.5 (4.1)	4.9 (5.9)	3.9 (3.6)
Total Copepoda	36.2 (51.6)	12.7 (4.2)	28.4 (40.9)	22.2 (19.4)	28.6 (23.4)
Total	145.3 (247.2)	44.1 (19.6)	120.7 (199.3)	58.7 (37.0)	67.6 (42.7)
1975					
Rotifera	12.9 (13.5)	5.9 (3.8)	10.2 (9.5)	7.6 (5.3)	12.4 (7.3)
Cladocera	69.8 (13.7)	41.2 (1.0)	63.4 (12.9)	58.0 (57.0)	46.4 (8.2)
Daphnia sp.	41.3 (9.3)	19.9 (0.0)	38.8 (8.8)	53.1 (54.7)	39.7 (7.8)
[illegible]	[illegible]	[illegible]	[illegible] (1.0)	3.1 (.05)	1.5 (.4)
Adult Copepoda	11.7 (10.6)	3.5 (.62)	9.4 (8.9)	11.0 (19.9)	10.5 (11.2)
Adult *C. vernalis*	6.7 (2.8)	3.5 (.3)	6.3 (2.2)	5.5 (14.8)	8.2 (8.6)
Nauplii	3.2 (3.4)	2.7 (.27)	2.5 (2.4)	3.5 (.94)	3.1 (3.6)
Total Copepoda	16.7 (15.3)	7.4 (4.5)	11.9 (11.3)	16.8 (24.4)	15.1 (15.6)
Total	99.4 (42.5)	54.5 (49.5)	85.5 (33.7)	82.4 (86.7)	73.9 (31.1)

* Number in parentheses is the mean biomass at the surface.

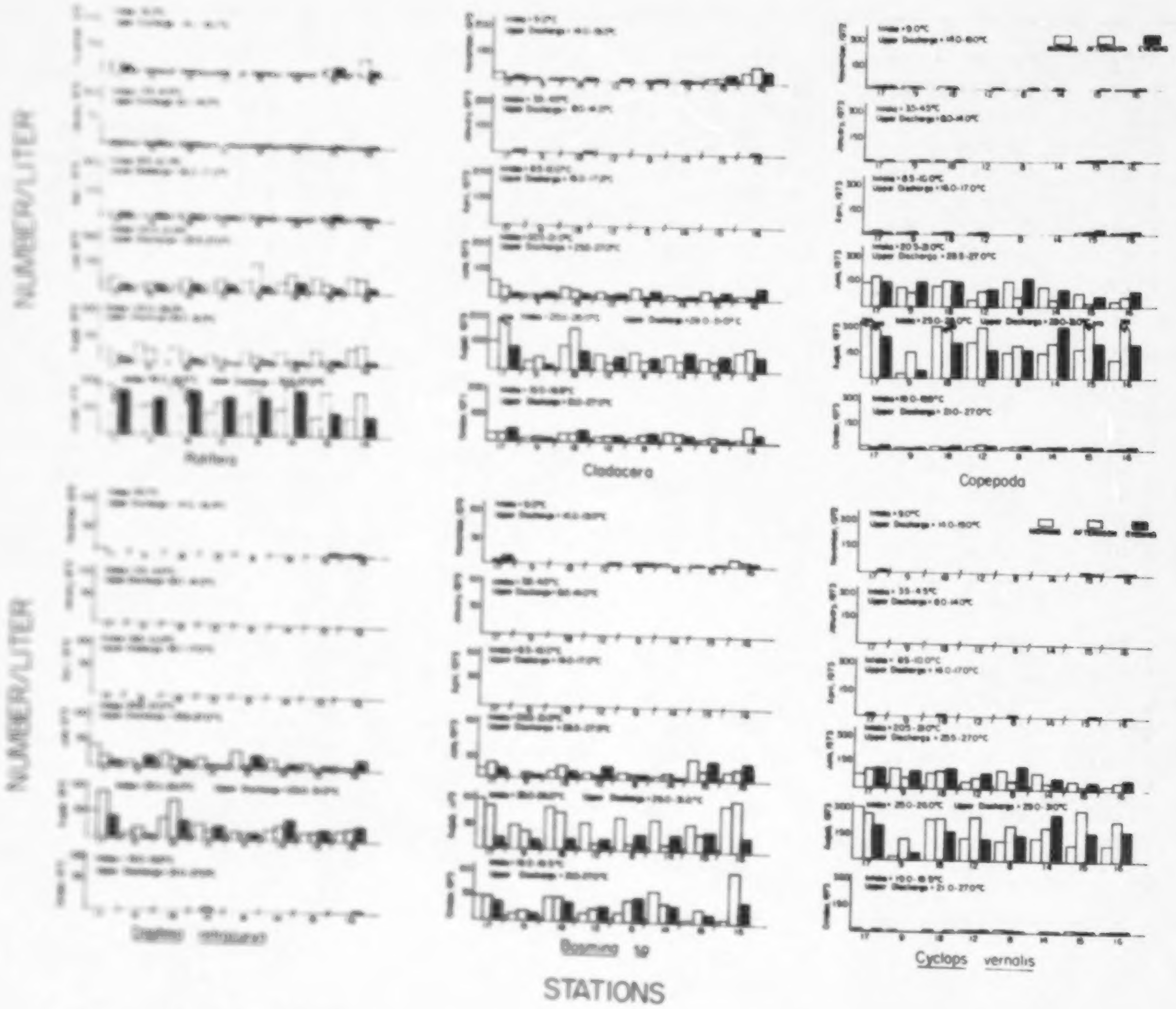


Figure 11. Mean densities of zooplankton in the cooling system at the Monroe Power Plant.

Abundances varied less dramatically over the short-term periods when the cooling system was sampled in the morning, afternoon, and evening of 1972-73 (Fig. 11). Even so, the abundances found at different times of the day commonly varied up to 100 percent or more of the mean. However, there was no consistent relationship between the abundance and the time of the day sampled. Mean annual densities for different times of the day revealed no consistant differences related to the time of the day (Table 23). Density differences between day and night were inconsistant and less than 50 percent among the major taxa. The densities of major taxa seemed to vary independently from one time of day to the next. There may have been a slight tendency for larger organisms to be captured more frequently at night. The mean individual size calculated in 1972-73 was slightly greater in the evening samples, particularly for C. vernalis and D. retrocurva (Table 24).

The short-term density comparisons revealed no consistent effects from regular chlorine application in the morning and evening. If chlorine had been important, the morning and evening zooplankton concentrations in the upper discharge canal at station 12 should have been consistently lower than afternoon concentrations in 1972-73 (Tables 21; 22). Because chlorinated water reached station 8 from 4 to 6 hours later, afternoon densities at station 8 should have been depressed below morning and evening densities if chlorine were an important factor. To the contrary, densities at station 12 and 8 were similar for all times.

Consistent trends appeared in the comparisons of annual station means (Tables 21, 22), but significant ($\alpha = 0.05$) differences rarely occurred at the individual sampling times because the sampling intensity was not enough to accommodate the spatial variability that existed. Lake concentrations at intake station 17 averaged about twice as great as river concentrations at station 9 and these consistent differences were significant ($\alpha = 0.05$) on several dates for most of the taxa (Table B24). Among stations in the intake and discharge canals, the significant ($\alpha = 0.05$) differences may have been caused by naturally patchy distributions in the study area rather than by entrainment effects. However, discharge concentrations were significantly ($\alpha = 0.05$) lower 3 out of 9 times when zooplankton were common in 1973; they were never significantly higher. Although patchy distributions increased in variability, there appeared to be consistent depressions in abundances as a consequence of passage through the cooling system. Among the most abundant species caught in 1973, significant differences ($\alpha = 0.05$) were about equally represented by higher and lower concentrations in the discharge canal compared to the intake. The incidence of statistical difference seemed not to be related to absolute water temperature or the elevation at the condenser.

The mean annual density of zooplankton consistently decreased one third to two thirds in passage from the intake to the upper discharge canal in all three years (Table 21). The biomass decreased less consistently because the mean size of animals encountered seemed to vary. In passage from the upper to the lower discharge canal, the mean annual densities of most taxa remained about the same or increased slightly while mean annual biomass changed little or decreased slightly. Therefore, mean annual sizes of zooplankters seemed to remain constant or decreased slightly as water passed through the discharge canal (Table 25). These size changes during the passage were most pronounced in the cladocera which decreased in mean size about 40 to 60 percent. The small rotifers consistently seemed to increase in size while copepods varied inconsistently.

TABLE 23. MEAN ANNUAL SIZE PER INDIVIDUAL OF ZOOPLANKTON IN THE COOLING SYSTEM (μg)

Taxa	STATIONS 17	9	18	12	8
1972-73					
Rotifera	0.1 (0.1)*	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0.2 (0.2)
Cladocera	6.1 (4.8)	2.2 (0.6)	5.1 (4.7)	11.8 (4.9)	6.8 (4.7)
Daphnia sp.	9.9 (12.0)	14.0 (5.7)	11.6 (11.0)	10.7 (16.6)	9.8 (5.7)
Bosmina sp.	1.6 (5.3)	0.8 (0.8)	1.1 (.65)	0.8 (0.7)	0.6 (1.0)
Adult Copepoda	3.6 (3.1)	4.3 (9.5)	3.8 (3.4)	3.9 (3.6)	2.5 (3.3)
Adult *C. vernalis*	2.7 (3.0)	4.0 (9.9)	3.2 (3.3)	3.4 (3.5)	2.7 (3.2)
Nauplii	0.2 (0.2)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
Total Copepoda	2.5 (2.2)	2.8 (2.6)	2.7 (2.2)	2.9 (2.8)	1.7 (2.0)
Total	2.1 (1.7)	1.7 (0.8)	2.1 (1.5)	2.7 (1.9)	1.6 (1.2)
1973-74					
Rotifera	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	0.1 (0.2)	0.2 (0.1)
Cladocera	3.0 (6.0)	1.3 (0.3)	2.7 (5.3)	1.4 (0.4)	1.1 (1.8)
Daphnia sp.	9.3 (11.1)	17.0 (0.0)	9.4 (20.7)	6.3 (0.0	6.2 (3.3)
Bosmina sp.	0.7 (0.5)	0.5 (0.2)	0.7 (0.5)	0.4 (0.4)	0.6 (1.3)
Adult Copepoda	4.3 (5.3)	2.0 (2.0)	4.4 (6.3)	3.0 (2.4)	3.5 (3.6)
Adult *C. vernalis*	3.7 (3.2)	2.7 (2.0)	3.8 (2.5)	3.2 (2.4)	3.1 (3.4)
Nauplii	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.2)	0.1 (0.6)
Total Copepoda	0.6 (0.9)	0.4 (0.2)	0.5 (0.8)	0.5 (0.6)	0.6 (0.5)
Total	0.6 (0.9)	0.3 (0.2)	0.5 (0.8)	0.4 (0.3)	0.4 (0.3)
1975					
Rotifera	0.9 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)
Cladocera	4.0 (1.2)	7.8 (0.5)	3.8 (1.3)	6.7 (13.9	3.0 (4.1)
Daphnia sp.	6.2 (4.6)	8.3 (0.0)	6.4 (4.6)	37.9 (18.2)	13.7 (7.8)
Bosmina sp.	1.0 (0.7)	0.1 (0.9)	1.1 (0.5)	1.1 (0.4)	0.9 (0.4)
Adult Copepoda	4.2 (5.6)	3.2 (3.1)	4.5 (6.4)	3.9 (4.8)	3.2 (3.2)
Adult *C. vernalis*	4.5 (2.5)	3.5 (3.0)	7.0 (2.2)	3.0 (3.7)	3.6 (2.4)
Nauplii	0.2 (0.2)	0.2 (0.1)	0.2 (0.1)	0.2 (0.1)	0.2 (.94)
Total Copepoda	0.9 (0.7)	0.6 (1.8)	0.7 (0.6)	0.9 (1.9)	0.7 (0.8)
Total	0.5 (0.2)	0.8 (1.2)	0.6 (2.1)	0.8 (0.9)	0.7 (0.3)

* Number in parentheses is the mean individual size at the surface

TABLE 24. MEAN DENSITY OF ZOOPLANKTON AT DIFFERENT TIMES OF THE DAY
(numbers/liter)

	STATIONS							
	17		9		12		8	
Taxa	Afternoon	Evening	Afternoon	Evening	Afternoon	Evening	Afternoon	Evening
1972-73								
Rotifera	100.2	80.7	46.2	39.9	53.0	58.4	78.0	42.8
Cladocera	43.7	25.5	10.0	7.9	8.4	14.7	12.2	17.7
Daphnia sp.	18.2	7.7	3.6	3.3	14.7	12.2	3.7	7.5
Bosmina sp.	13.3	8.1	6.0	3.7	3.6	7.1	6.9	8.4
Adult Copepoda	73.3	56.7	42.3	28.1	57.1	40.3	43.6	49.7
Adult *C. vernalis*	62.6	52.8	30.2	22.0	51.8	35.8	42.7	42.9
Nauplii	26.7	110.6	25.0	11.6	21.7	9.5	31.4	20.7
Total Copepoda	100.0	167.3	67.3	39.7	78.8	49.8	75.0	70.4
Total	243.9	273.5	123.5	87.5	140.2	122.9	165.2	130.9
1973-74								
Rotifera	191.6	132.6	111.3	104.0	119.2	88.2	94.2	132.1
Cladocera	36.9	26.5	11.3	12.5	14.8	20.3	10.0	24.3
Daphnia sp.	14.7	3.3	.3	.6	3.3	2.6	3.0	1.3
Bosmina sp.	11.3	20.1	8.0	8.1	10.5	13.6	6.3	18.9
Adult Copepoda	4.2	8.0	3.2	3.9	.5	9.3	7.0	5.3
Adult *C. vernalis*	3.4	5.1	2.3	3.2	.4	6.7	4.4	3.3
Nauplii	73.8	36.0	24.1	20.6	40.9	37.6	48.2	36.3
Total Copepoda	78.0	44.0	27.3	24.5	41.4	46.9	55.2	41.6
Total	306.5	203.1	149.9	141.0	175.4	155.4	159.4	210.0
1975								
Rotifera	141.0	149.4	38.6	55.9	69.1	72.7	56.7	82.4
Cladocera	22.6	12.6	3.2	7.4	10.0	7.2	19.2	11.4
Daphnia sp.	8.6	4.6	1.2	3.6	1.2	1.6	2.0	3.8
Bosmina sp.	3.2	1.6	.34	1.3	2.8	2.8	.8	2.4
Adult Copepoda	2.0	3.6	.15	2.0	1.5	4.2	1.8	4.7
Adult *C. vernalis*	.4	2.6	.05	2.0	.4	3.2	1.2	3.4
Nauplii	19.3	11.9	11.6	11.5	17.2	14.4	19.5	15.7
Total Copepoda	21.3	15.5	11.75	13.5	18.7	18.6	21.3	20.4
Total	184.9	177.5	53.55	76.8	97.8	98.5	97.2	114.2

TABLE 25. MEAN SIZE PER INDIVIDUAL FOR THE MAJOR TAXA AT THE DAILY TIME PERIODS

	Taxa	Morning	Afternoon	Evening
1973:	Rotifera	0.1	0.1	0.1
	Cladocera	6.5	5.0	4.6
	Daphnia sp.	12.5	11.1	10.9
	Bosmina sp.	1.3	1.0	1.1
	Adult Copepoda	2.2	2.2	3.2
	Adult *C. vernalis*	2.8	3.0	5.0
	Nauplii	0.1	0.1	0.1
	Total Copepoda	1.7	1.7	2.7
	Total	2.7	2.3	2.5
1974:	Rotifera	--	0.1	0.1
	Cladocera	--	2.5	1.5
	Daphnia sp.	--	7.2	10.4
	Bosmina sp.	--	0.6	0.6
	Adult Copepoda	--	2.6	4.0
	Adult *C. vernalis*	--	2.4	3.6
	Nauplii	--	0.1	0.1
	Total Copepoda	--	0.3[a]	0.8
	Total	--	0.3[a]	0.4[a]
1975:	Rotifera	--	0.1	0.1
	Cladocera	--	3.7	5.8
	Daphnia sp.	--	7.6	15.5
	Bosmina sp.	--	1.0	0.8
	Adult Copepoda	--	4.1	3.5
	Adult *C. vernalis*	--	3.6	3.6
	Nauplii	--	0.2	0.2
	Total Copepoda	--	0.5[a]	0.9
	Total	--	0.6[a]	0.7

[a] Low value a result of large numbers of nauplii and rotifers.

Based on day and night comparisons, there was no significant diurnal, vertical migration in any of the major taxa but cladocerans and copepods exhibited depth-biased distributions (Fig. 12). On several dates, both of these taxa were more abundant near the bottom than near the surface at three of the four stations (17, 9, 12 and 8) where depths were randomly sampled over 5-m from top to bottom. Other stations were too shallow to sample similarly. The time of day did not seem to influence the vertical orientation, but it did not occur equally on all dates sampled. No depth biased distribution was ever observed in the upper discharge canal (station 12). On the dates when vertically biased distributions occurred, condenser passage caused uniform vertical distribution. Whatever disrupted this effect ceased after the water mass approached the middle of the discharge canal at station 8.

Based on the mixing measured by chloride concentrations, the concentration of zooplankton in the thermal plume was expected to be a mixture of populations in the lake receiving water and populations that had passed through the cooling system at least once. Sampling in 1972-73 verified this proposition. By the time that water from the cooling system and the lake mixed back to ambient chloride concentrations and temperatures at station 16, zooplankton concentrations also mixed back to concentrations like those found in the lake reference areas (Table 26).

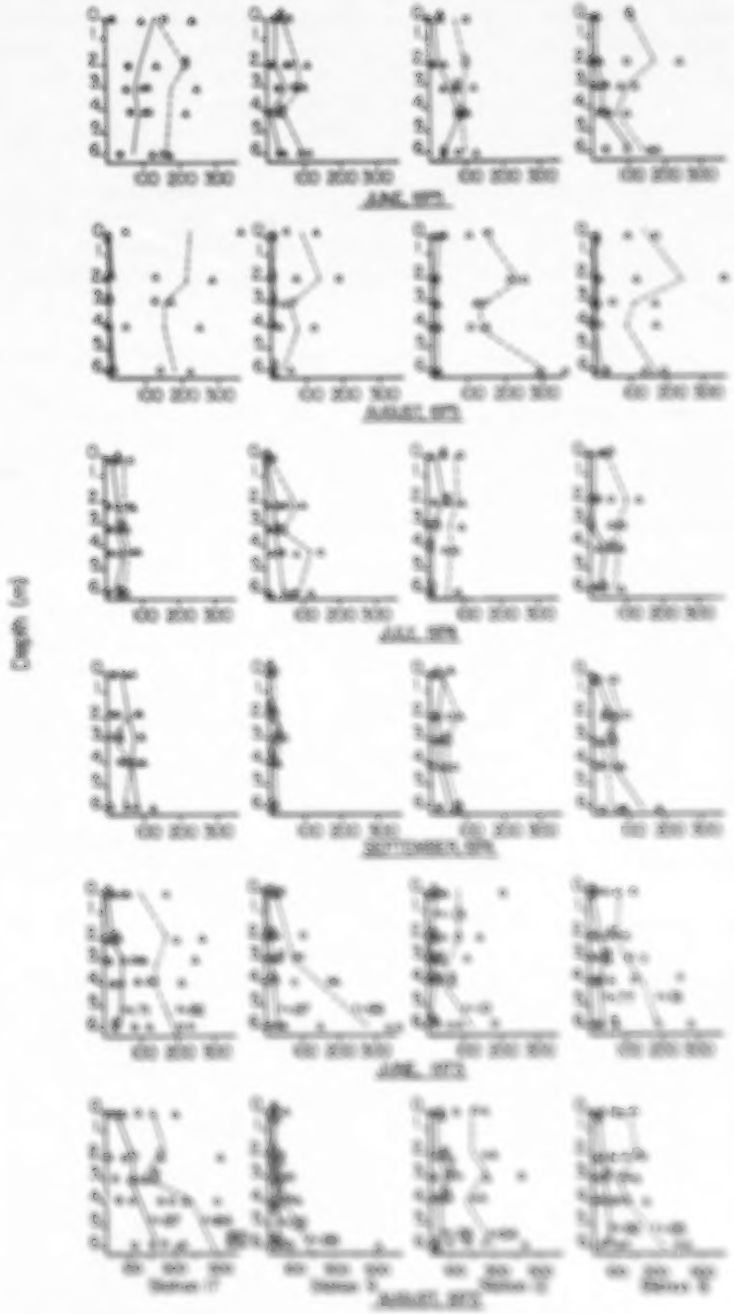
As at station 16, sampling at station 15 was conducted only at the surface (0.5 m) because the thermal plume tended to float and the water depth averaged only 1 to 1.5 m. Station 15 was located about midway between the mouth of the discharge canal and the plume edge at a point where temperature and chloride concentration averaged close to midway between the conditions in the discharge canal and the lake. Based on mixing ratios defined by chloride concentration and temperature, zooplankton concentrations in the plume at station 15 were expected to average midway between those at stations 14 and 16. This they tended to do but sampling variability obscured differention of concentrations estimated at station 15 from population estimates for other locations in the study area.

Mortality

Pilot studies of mortality conducted to assess the potential at times of the year when zooplankton were abundant and temperatures in the cooling system would approach 30°C or more (June and July). In 1974, sampling was directed at the smaller zooplankters and in 1976 it concentrated on the relatively large *Leptodora kindtii*. The mean percent that were dead in the intake and discharge canal is summarized in Table 27. From 8 to 19 percent of the organisms were dead in the intake reference collections. For the rotifers and nauplii, the smallest plankters, an average of 7 to 8 percent were dead in the discharge canal. The percent dead averaged 12 percent for the intermediate-sized copepods. For the class with the largest organisms, the percentage averaged 26% dead.

The largest zooplankter, *Leptodora kindtii*, averaged 60 percent dead in the cooling system. Only the Cladocera, and particularly the largest cladocerans, appeared to be appreciably affected by the condenser passage.

This data is insufficient by itself to demonstrate the impact of power plant operation on zooplanktonic survival. It does point out the need for further



mg/m³

Figure 12. Mean density of copepods (open) and cladocerans (closed) at each depth sampled for the summers of 1973, 1974, 1975.

TABLE 26. COMPARISON OF MEAN DENSITY, BIOMASS, AND SIZE OF ZOOPLANKTON AMONG THE LAKE STATIONS AND LOWER DISCHARGE STATION 14 AT 0.5 m BELOW THE SURFACE* IN 1973

Taxa	Station						
	3#	4#	5#	14	15	16	17
				Density			
Rotifera	107.0	109.0	90.0	83.0	70.3	78.8	81.5
Cladocera	30.2	27.6	18.8	16.4	24.0	41.0	25.2
Total Copepoda	106.7	70.6	101.8	114.3	111.2	112.6	144.7
Total	243.9	207.2	210.6	213.7	205.6	232.4	251.4
				Biomass			
Rotifera	9.8	10.9	12.8	8.2	8.7	8.5	8.9
Cladocera	162.8	110.6	59.7	59.5	52.3	79.1	86.1
Total Copepoda	115.5	141.4	92.7	172.0	265.9	218.7	209.0
Total	288.1	262.9	165.2	239.7	326.9	306.3	304.0
				Mean Size/Individual			
Rotifera	0.09	0.10	0.14	0.10	0.12	0.11	0.11
Cladocera	5.4	4.0	3.2	3.6	2.2	1.9	3.4
Total Copepoda	1.1	2.0	0.9	2.1	2.4	1.9	1.4
Total	1.2	1.3	0.8	1.1	1.6	1.3	1.2

*Only samples collected from April to November, 1973, are included because no winter samples were taken at stations 3, 4, and 5.

#Data from Cole (1976).

TABLE 27. PRELIMINARY ESTIMATE OF ZOOPLANKTON MORTALITY IN THE COOLING SYSTEM AT THE MONROE POWER PLANT
(percent dead)

Station	Leptodora kindtii[*]	Copepoda[#]	Nauplii[#]	Cladocerans[#]	Rotifers[#]
Intake (18)	10	8	15	19	9
Upper Discharge (12)	60	16	9	17	6
Middle Discharge (8)		7	6	50	3
Lower Discharge (14)		25	13	10	17

[*] Mean of three replicates sampled on July 6 through 9, 1976.

[#] Mean of three replicates sampled on June 27, 1974.

investigations on what may be size-selection or other taxa-specific, selective mortality in the cooling system.

Diversity

Zooplanktonic diversity did not consistently change with passage through the cooling system. Organisms were abundant enough to contrast diversity only during warm months (Table 28). Differences in diversity over a three-day period at specific stations were often as great as differences observed among stations on any particular date. There were no consistent trends in diversity related to the time of sampling. Short-term variations appeared to be caused primarily by spatial variability among samples at each station and may have been effected secondarily by patchy distributions associated with different water masses. Entrainment seemed to have little effect on diversity.

MIDGES

Chironomid entrainment was estimated in 1973 at the time we tentatively investigated larval fish distributions in the cooling system. Midges were transported through the cooling system as larvae and pupae (Table 29). Most midges were captured in the deepest tows, at 4 m. Because the tow depth was 2 m or more over the bottom at most sites, the actual number of midges entrained was probably underestimated by the averages generated from the data. Estimates of numbers varied widely over the sampling period, but river abundances appeared to exceed lake abundances. At rates estimated for the sampling period, an average of 700,000 midges per day could pass through the plant at full operation.

LARVAL FISH

Species Composition

The most abundant of 15 taxa captured from 1973-1975 included gizzard shad, *Dorosoma cepedianum*, and the alewife, *Alosa pseudoharengus* (together 43.6 percent; hereafter referred to as "clupeids"); yellow perch, *Perca flavescens* (25.3 percent); carp, *Cyprinus carpio*, goldfish, *Carassius auratus*, and their hybrids (together 10.6 percent); white bass, *Morone chrysops* (7.3 percent); emerald and spottail shiners, *Notropis atherinoides* and *N. Hudsonius* (together 3.2 percent); and freshwater drum, *Aplodinotus grunniens* (2.0 percent). The combinations of species listed above could not be routinely separated to species as larvae. These species accounted for 92 percent of the total catch. Prolarvae (yolk-sac larvae) represented 19.1 percent of the total catch and postlarvae represented 80.9 percent. Less abundant species are listed in Tables 30 and B26.

Comparison of Surface Sampling Techniques

The 1-m plankton net was the most effective surface sampling technique tested in the comparison of the Kenco pump, the high-speed plankton sampler, and the 571-μ, 1-m, plankton net. Significantly ($\alpha = 0.05$) more fish larvae of all species were captured by the 1-m net on most of the dates sampled (Table B27); white bass were captured only in the 1-m net (Table 31).

TABLE 28. ZOOPLANKTON DIVERSITY IN THE COOLING SYSTEM

		Station				
	Date	17	9	18	12	8
1973:	06/11	0.53	0.59	0.53	0.57	0.59
	06/12	0.70	0.51	0.59	0.73	0.78
	08/08	0.42	0.49	0.45	0.50	0.43
	08/09	0.48	0.69	0.64	0.40	0.45
	09/28	0.84	0.76	0.92	0.87	0.95
	09/29	0.81	0.83	0.83	0.93	0.96
1974:	06/11	0.98	1.08	1.00	0.81	1.00
	06/12	0.70	1.08	0.78	0.94	0.94
	08/14	0.63	0.94	0.67	0.92	0.82
	08/15	0.51	0.90	0.54	0.72	0.81
	10/19	0.66	0.64	0.66	0.67	0.67
	10/21	0.74	0.60	0.73	0.65	0.67
1975:	05/16	0.59	0.80	0.67	0.62	0.84
	05/17	0.55	0.78	0.67	0.76	0.68
	07/27	0.72	0.99	0.73	0.87	0.80
	07/28	0.81	0.92	0.82	1.06	1.00
	09/15	1.01	0.59	0.95	0.94	1.00
	09/16	0.91	0.89	0.91	1.10	0.86

TABLE 29. THE DISTRIBUTION OF CHIRONOMID LARVAE IN THE COOLING SYSTEM IN 1973

(no./100 m^3)

Date and Depth*	Station P_1	 P_2	 P_3	 P_4	 P_{11}
1 May 1973					
0.0 m	1.0[#]	4.0	1.5	3.5	0
2.5 m	--	--	--	--	--
4.0 m	3.0	17.0	14.0	--	--
Mean	2.0	10.5	7.8	3.5	0
15 May 1973					
0.0 m	0.5	1.0	1.5	1.2	0.5
2.5 m	0.0	1.5	3.0	--	0.0
4.0 m	3.0	10.0	13.0	--	0.5
Mean	1.2	4.2	5.8	1.2	0.3
1 June 1973					
0.0 m	3.5	1.5	1.0	0.2	6.5
2.5 m	15.5	0.0	12.0	--	1.0
4.0 m	28.0	24.0	8.0	--	1.0
Mean	15.7	8.5	7.0	0.2	2.8
8 June 1973					
0.0 m	0.8	3.3	0.5	1.8	1.0
15 June 1973					
0.0 m	0.5	3.0	6.0	0.3	0.0
2.5 m	0.0	47.0	2.0	--	3.0
4.0 m	13.0	500.0	19.0	--	2.0
Mean	4.5	183.3	9.0	0.3	1.7

*Maximum depth is 1.5 meters

[#] Mean of 2 replicates

TABLE 30. MEAN CATCH OF FISH LARVAE PER 100 m^3 IN OBLIQUE 1-m PLANKTON NET TOWS FROM MAY THROUGH JULY IN 1974* AND 1975 #

	P_6		P_7		P_2		P_3		P_{10}		P_{11}		P_{12}	
	74	75	74	75	74	75	74	75	74	75	74	75	74	75
Clupeids	13.7	7.8	3.6	2.3	17.0	11.0	15.4	6.7	9.5	8.5	36.8	9.0	20.4	3.8
Yellow perch	15.0	9.7	1.6	0.4	11.7	7.1	6.2	0.6	7.6	5.6	1.5	2.5	1.0	13.2
Carp-goldfish	1.4	0	12.7	3.8	10.7	4.1	3.5	0.9	0.2	0	0.2	0	0.8	0
White bass	2.4	0.6	0.1	1.1	14.5	1.3	3.5	0.4	1.0	0.4	1.5	0.8	2.6	0.5
Shiners	0.5	0.2	0.4	3.6	2.5	2.6	0.5	0.1	0.7	0.4	0.8	0.8	1.6	0.2
Freshwater drum	2.4	0	2.1	0	3.0	0	1.1	0.1	1.7	0.1	1.2	0	0.8	0
Smelt	0.1	0.4	0.1	0.5	0	0.5	0	0	0.2	0.2	0.4	0.1	0.1	0.5
Sunfish	0.7	0	1.9	1.0	1.1	0.2	0.6	0.2	0.1	0	0.1	0	0.2	0
Black bass	0	0	0.9	0.5	0.1	0	0	0	0	0	0	0	0.3	0.1
Channel catfish	0.1	1.0	0.1	0.3	4.0	0.3	0.5	0	0	0	0	0	0	0
Crappie	0	0	0.3	0.5	0	0.1	0	0	0	0	0	0	0.1	0
Trout perch	0.1	0.1	0	0	0.1	0	0	0	0	0	0	0	0	0
Log perch	0.1	0	0	0	0	0.3	0	0	0	0	0	0	0	0
Walleye	0.2	0	0	0	0.1	0	0	0	0	0	0	0	0	0
White sucker	0.1	0	0	0.4	0	0	0	0	0	0	0	0	0	0
Total	36.8	18.8	21.4	15.4	64.8	27.5	31.3	9.0	21.0	15.2	42.5	13.2	27.9	18.3

*Sampled on 6 dates; 5 replicates/date

#Sampled on 5 dates; 5 replicates/date

TABLE 31. COMPARISON OF THE MEAN CATCH AT THE SURFACE IN A 571-μ, 1-m PLANKTON NET, A MODIFIED HARDY "HIGH-SPEED" SAMPLER, AND A KENCO PUMP*
(number/100 m^3)

	05/21/75	05/23/75	05/24/75	06/18/75	06/19/75	06/20/75	Total
Clupeids							
1-m net	0*	2.8	0	62.1	8.3	0	73.2
High-speed	0	0	0	343.7	0.9	0	344.6
Pump	0	0	0	21.3	0	0.7	22.0
Yellow perch							
1-m net	4.3	3.7	0	0.7	0	0	8.7
High-speed	0	0	0	5.3	0	0	5.3
Pump	0	0	0	0	0	0	0
White bass							
1-m net	0	0	0	0.7	0	0	0.7
High-speed	0	0	0	0	0	0	0
Pump	0	0	0	0	0	0	0
Smelt							
1-m net	1.4	0.8	0	8.7	0	0	10.9
High-speed	0	0	0	0.9	0	0	0.9
Pump	0	0	0	0	0	0	0
Shiners							
1-m net	0	0	0	9.3	0	0	9.3
High-speed	0	0	0	0.9	0	0	0.9
Pump	0	0	0	0	0	0	0
Total							
1-m net	5.7	7.3	0	63.5	8.3	0	84.8
High-speed	0	0	0	350.8	0.9	0	351.7
Pump	0	0	0	21.3	0	0.7	22.0

*5 replicates

The Kenco pump was the least effective sampling technique tested. Significantly ($\alpha = 0.05$) fewer larvae of all taxa were captured (Table B27). Fish larvae were captured only on June 18 and 19 when clupeids were common. About 40 percent of the captured larvae were damaged; 10 percent were damaged so badly they could not be identified or included in the statistical analysis.

The high-speed plankton sampler seemed most effective when fish larvae were dense at the surface (Table 31). This occurred only on June 18, when more ($p \leq 0.05$) yellow perch and clupeid larvae were captured with the high-speed sampler than with the other surface techniques (Table B26). On all other dates the 1-m plankton net performed best.

Mean Size and the Length of Time Towed

The 353-μ, 1-m net usually caught more fish larvae than 1-m nets with larger mesh sizes (Figure 13). The 1000-μ nets caught fewer ($p \leq 0.05$) larvae than the 363-μ or 571-μ nets. The 760-μ net caught fewer ($p \leq 0.05$) larvae than the smaller mesh sizes on one of two dates that it was compared.

The relative capture effectiveness of the two smaller mesh sizes appeared to depend on the species and size (age) of the larvae (Table 23). Prolarval fish were caught most effectively with the 363-μ net. On May 21, more ($\alpha = 0.05$) smelt prolarvae were caught with the 363-μ net compared to the others (Table B27). On May 20, more ($p \leq 0.05$) yellow perch postlarvae were caught with the 571-μ net. On June 21, more ($p \leq 0.05$) postlarval clupeids were captured using the 363-μ net.

No consistently significant ($\alpha = 0.05$) large differences appeared between 1, 2, 3, 4, and 5-min tows (Fig. 13; Table B28). The 1, 2, and 3-min tows averaged slightly more fish larvae per unit effort but the 5-min tow caught more fish larvae per unit effort than the others on one of the sampling dates.

Vertical Distributions

Daytime Tows--

Oblique tows from deep water to surface usually were as effective as the mean of stratified tows made at the surface and deep position at the transect stations P13, P14, P15, and P16. Minor difficulties in species suseptibility may have existed. Clupeids and smelt tended to be captured more effectively with stratified tows although the capture rate was not statistically different ($\alpha = 0.05$) from the oblique tows. Yellow perch and white bass tended to be caught more efficiently with oblique tows (Fig. 14). No consistent differences in the catch effectiveness of stratified and oblique tows appeared anywhere along the transect, regardless of distance from shore or differences in depth to the bottom.

At station P17, the daytime capture efficiency at different depths was inconsistent in time and by species but in no instance did the mean of oblique and stratified tows differ (Table 32). Fish larvae appeared to be concentrated near the bottom during the day (according to bottom-sled yield) but populations above the bottom exhibited no consistent vertical distributional

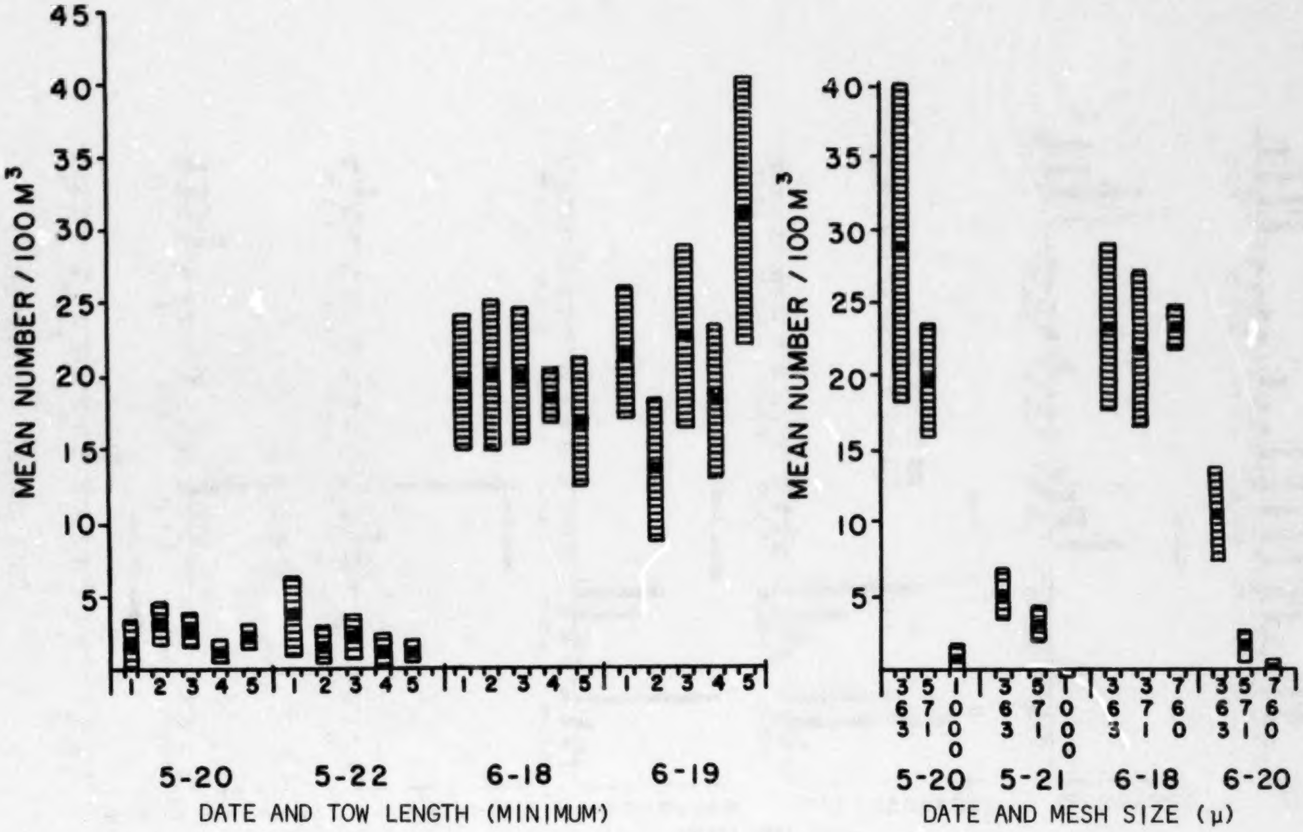


Figure 13. The mean number of larval fish captured ($\pm$SE) for length of time towed (1, 2, 3, 4, and 5 min.) and each mesh size tested (363, 571, 760 and 1000μ).

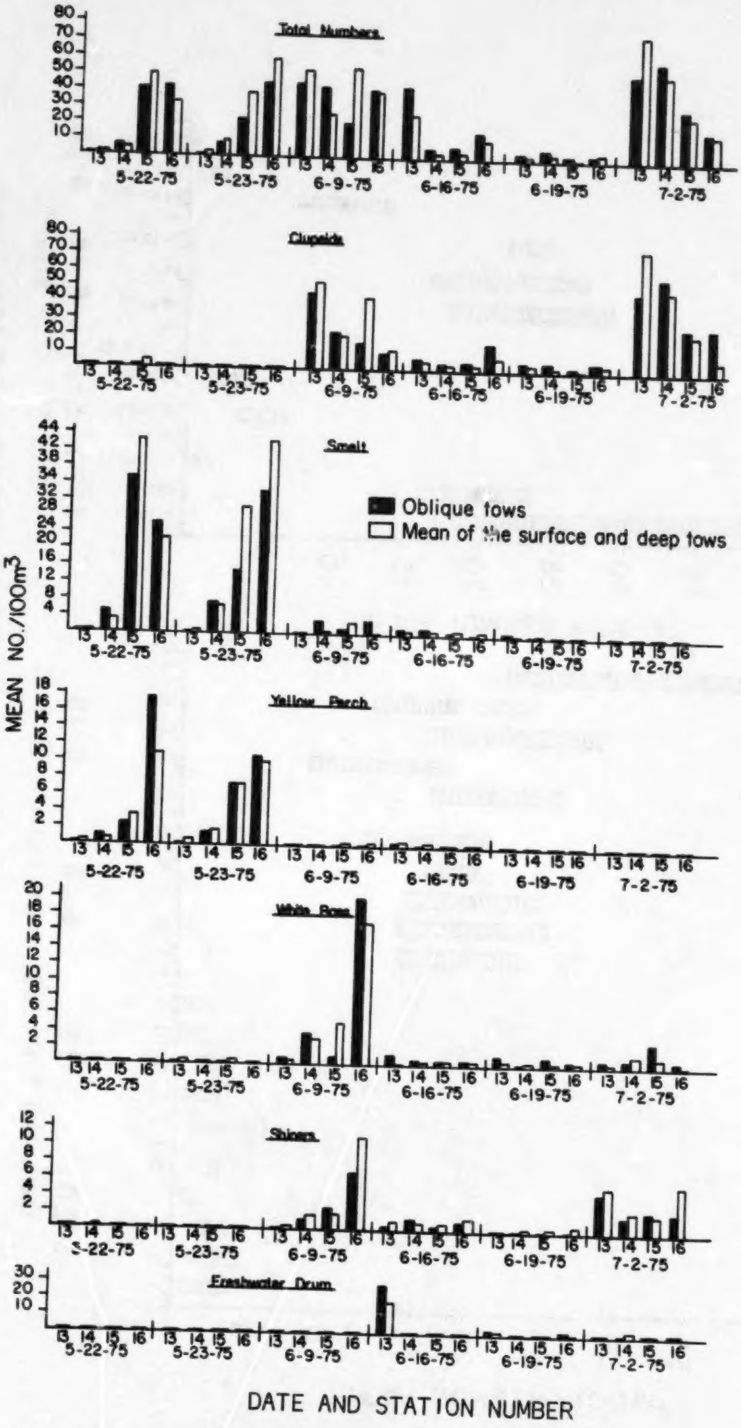


Figure 14. Mean number of larval fish captured in oblique tows compared to the mean of stratified tows at the surface and bottom.

TABLE 32. DAYTIME AND NIGHTTIME COMPARISONS OF MEAN CATCH (5 replicates) per 100 m³ IN OBLIQUE, SURFACE, MIDWATER, DEEP TOWS AND TOWING WITH A BOTTOM SLED USING A 571-μ, 1-m PLANKTON NET

Species	Surface	Midwater	Deep	Mean*	Oblique	Bottom Sled	Water Column Mean #
Clupeids							
5/21/75							
Day	0	0	0	0	0.9	--	0
Night	2.2	3.4	5.2	3.6	4.3		18.0
5/23/75							
Day	2.8	0.5	0	1.1	1.2	--	5.5
Night	0	0.6	0.5	0.4	1.8		1.8
5/24/75							
Day	0	0	0	0	0.3	--	0
Night	0	1.7	0	0.6	0.7		2.8
6/18/75							
Day	62.1	21.9	3.3	29.1	12.7	698.6	815.0
Night	81.0	89.3	94.9	88.4	89.4		442.0
6/19/75							
Day	8.3	1.3	0	3.3	7.4	81.1	93.9
Night	45.0	88.9	64.1	66.0	103.5		330.0
6/20/75							
Day	0	1.1	0.5	0.5	1.2	124.2	126.3
Night	3.2	6.8	0.5	3.5	2.6		17.5
Mean							
Day	12.4	4.4	0.6	5.7	3.4	301.3	173.4
Night	21.9	31.8	27.5	27.1	33.7		135.4

(continued)

TABLE 32 (continued).

Species	Surface	Midwater	Deep	Mean*	Oblique	Bottom Sled	Water Column Mean#
White Bass							
5/21/75							
Day	0	0	0	0	0	--	0
Night	0	0.6	0	0.2	0		1.0
5/23/75							
Day	0	0.6	1.1	0.6	0.5	--	3.0
Night	0	0	0	0	0		0
5/24/75							
Day	0	0	0.7	0.2	0	--	1.0
Night	0	0	0	0	0		0
6/18/75							
Day	0.7	1.6	2.8	1.7	2.3	36.7	43.5
Night	6.6	7.3	5.8	6.6	4.9		32.8
6/19/75							
Day	0	0.5	0	0.2	0	27.0	27.8
Night	0	5.0	1.0	2.0	1.2		10.0
6/20/75							
Day	0	0	0	0	0	25.1	25.1
Night	0.8	10.8	9.2	6.9	9.6		34.7
Mean							
Day	0.1	0.5	0.8	0.5	0.5	29.6	16.7
Night	1.2	4.0	2.7	2.6	2.6		13.1

(continued)

TABLE 32 (continued).

Species	Surface	Midwater	Deep	Mean*	Oblique	Bottom Sled	Water Column Mean #
Yellow Perch							
5/21/75							
Day	4.3	2.2	1.6	2.7	0.9	--	13.5
Night	29.0	57.7	32.7	39.8	33.5		199.0
5/23/75							
Day	3.7	0.5	0.5	1.6	2.0	--	8.0
Night	0	3.6	35.1	12.9	17.9		64.5
5/24/75							
Day	0	0.7	0.7	0.5	2.0	--	2.5
Night	1.3	13.0	31.3	15.2	23.1		76.0
6/18/75							
Day	0.7	0	3.0	1.2	0.3	0.0	4.8
Night	1.1	7.6	7.3	5.3	9.7		26.7
6/19/75							
Day	0	0	1.0	0.3	0	11.0	12.2
Night	0	3.0	10.4	4.5	2.2		22.3
6/20/75							
Day	0	0	0	0	0	3.9	3.9
Night	0	0	4.3	1.4	0.9		7.2
Mean							
Day	1.5	1.1	2.3	1.2	1.2	6.2	7.5
Night	5.2	14.2	20.2	13.2	14.6		65.9

(continued)

TABLE 32 (continued).

Species	Surface	Midwater	Deep	Mean*	Oblique	Bottom Sled	Water Column Mean#
Smelt							
5/21/75							
Day	1.4	2.7	1.1	1.7	3.5	--	8.7
Night	18.5	11.8	13.4	14.6	10.2		72.8
5/23/75							
Day	0.7	0.6	1.1	0.8	1.5	--	4.0
Night	8.3	35.1	46.6	30.0	42.5		150.0
5/24/75							
Day	0	0	1.2	0.4	0.2	--	2.0
Night	17.5	61.0	29.1	35.9	44.2		179.3
6/18/75							
Day	8.7	5.7	8.1	7.5	7.2	632.0	662.0
Night	6.3	11.3	15.1	10.9	10.0		54.5
6/19/75							
Day	0	0.5	0.5	0.3	0.7	27.7	28.0
Night	0	2.5	0.9	1.1	0.2		5.7
6/20/75							
Day	0	0	0	0	0	2.6	2.6
Night	0.8	3.4	13.3	5.8	0.9		29.2
Mean							
Day	1.8	1.6	2.0	1.8	2.2	222.9	117.9
Night	8.6	20.8	19.7	16.4	18.0		81.9

(continued)

TABLE 32 (continued)

Species	Surface	Midwater	Deep	Mean*	Oblique	Bottom Sled	Water Column Mean#
Shiners							
5/21/75							
Day	0	0	0	0	0	--	0
Night	0.6	0	0	0.2	0		1.0
5/23/75							
Day	0	0	0	0	0	--	0
Night	1.4	0	0	0.5	0.7		2.3
5/24/75							
Day	0	0	0	0	0	--	0
Night	0.7	1.2	0	0.6	0.5		3.2
6/18/75							
Day	9.3	2.1	3.2	4.9	7.3	33.5	53.1
Night	6.9	7.6	7.3	7.3	6.5		36.3
6/19/75							
Day	0	0	0	0	0	3.2	3.2
Night	2.4	0.5	0.5	1.1	0.2		5.7
6/20/75							
Day	0	0.6	0	0.2	0	2.6	2.8
Night	0.9	2.0	0.5	1.1	1.8		5.7
Mean							
Day	1.6	0.5	0.5	0.9	1.2	6.6	9.8
Night	2.2	1.9	1.4	1.8	1.6		9.0

(continued)

TABLE 32 (continued)

Species	Surface	Midwater	Deep	Mean*	Oblique	Bottom Sled	Water Column Mean #
Carp							
5/21/75							
Day	0	0	0	0	0	--	0
Night	0	0	0	0	0		0
5/23/75							
Day	0	0	0	0	0	--	0
Night	0	0	0	0	0		0
5/24/75							
Day	0	0	0	0	0	--	0
Night	0	0	0	0	0		0
6/18/75							
Day	0	0	0	0	0	12.9	12.9
Night	4.0	5.3	2.9	4.1	3.1		20.3
6/19/75							
Day	0	0	0	0	0	9.0	9.0
Night	8.1	24.0	53.2	28.4	29.9		142.2
6/20/75							
Day	0	0	0	0	0	0.6	0.6
Night	70.2	130.7	61.4	87.4	80.6		437.2
Mean							
Day	0	0	0	0	0	7.5	7.5
Night	13.7	26.7	19.6	20.0	18.9		99.9

*Mean of surface, midwater and deep tows.

#Weighted mean of all strata, including bottom sled yield, for a 5 m depth.

patterns. For example, ($p \leq 0.05$) yellow perch prolarvae were captured using surface and mid-water tows (Table B29) on May 21 and 23 than in deep or oblique tows; but on May 24 no yellow perch prolarvae were captured at the surface even through they were captured in all other tows. Similarly, the catches of clupeid and shiner larvae at the three discrete depths usually did not significantly ($\alpha = 0.05$) differ from one another. On exceptional dates, more ($p \leq 0.05$) clupeids were captured at the surface (June 19) and fewer ($p \leq 0.05$) shiners were captured in mid-water (June 18). Much of the inconsistent variation that occurs in vertical distribution above the bottom appears to be caused by day to day vertical changes in the clumped distribution of larvae.

When the 571-μ, 1-m plankton net was towed on a bottom sled, it yielded more ($p \leq 0.05$) fish larvae of the important species than the sum of all netting at the other three strata sampled above the bottom (Table 32). Capture rates with the bottom sled were greatest on June 18 when clupeids and smelt dominated the catch. On this date, over 100 times more larvae were captured with the bottom sled than with all of the other tows tested. Daytime catches of all taxa were greatest with the bottom sled. It appears that more larvae concentrated near the bottom during the day, but any larvae caught above that bottom concentration exhibited no consistent stratification.

Nighttime tows--

Nighttime capture rates in the water column above the bottom averaged at least two to three times the daytime capture rates (excluding the bottom sled) for all of the major taxa (Fig. 15). The ratios ranged from 1.5:1 to 49:1. The nighttime capture rates of yellow perch, white bass, and freshwater drum were significantly ($\alpha = 0.05$) greater than daytime capture rates on all dates sampled. On most dates, nighttime capture rates of clupeids, smelt, and shiners also were significantly ($\alpha = 0.05$) less than daytime rates. The mean ratios over all sampling dates of nighttime to daytime captures were: freshwater drum, 14.3; yellow perch, 5.5; smelt, 5.0; clupeids, 4.1; white bass, 3.4; and shiners, 2.4. Although the nighttime ratios of most larval taxa captured at each depth were not always consistent for the whole sampling period, deep catches tended to exceed surface catches. Compared to other species, relatively more yellow perch and smelt were caught near the bottom at night, while relatively more shiners and clupeids were caught closer to the surface.

Distribution in Relation to Distance From Shore

Daytime larval distribution along a 16-km transect perpendicular to shore revealed species specific gradients on dates when larvae were relatively abundant. Clupeids were relatively abundant at near-shore stations (Fig. 16) where on June 9 and July 2 these stations yielded significantly ($\alpha = 0.05$) more larvae (Table B30). Yellow perch prolarvae were significantly ($\alpha = 0.05$) more abundant at offshore stations, as were smelt and, to a lesser extent, white bass and shiners. On May 22 and 23 yellow perch larvae were caught along a distinct gradient from shore with greatest abundance at station 16. White bass were captured mostly offshore at station P16. Freshwater drum were captured primarily on June 16 when most ($p \leq 0.05$) were captured near shore at station P13.

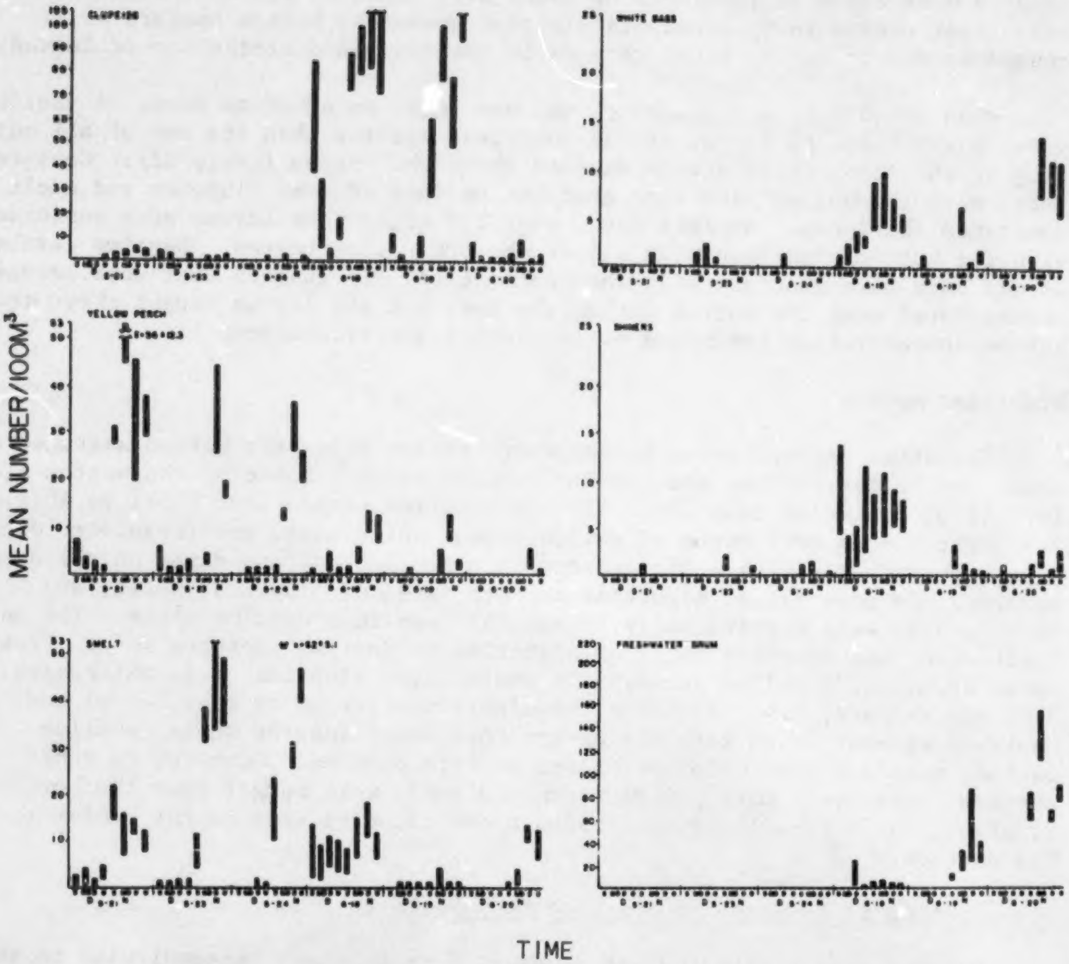


Figure 15. Mean number of larval fish captured (±SE) during the day (D) and night (N) for each depth stratum at station P 17 (S = surface; MD = mid-depth; D = deepwater; and O = oblique tow).

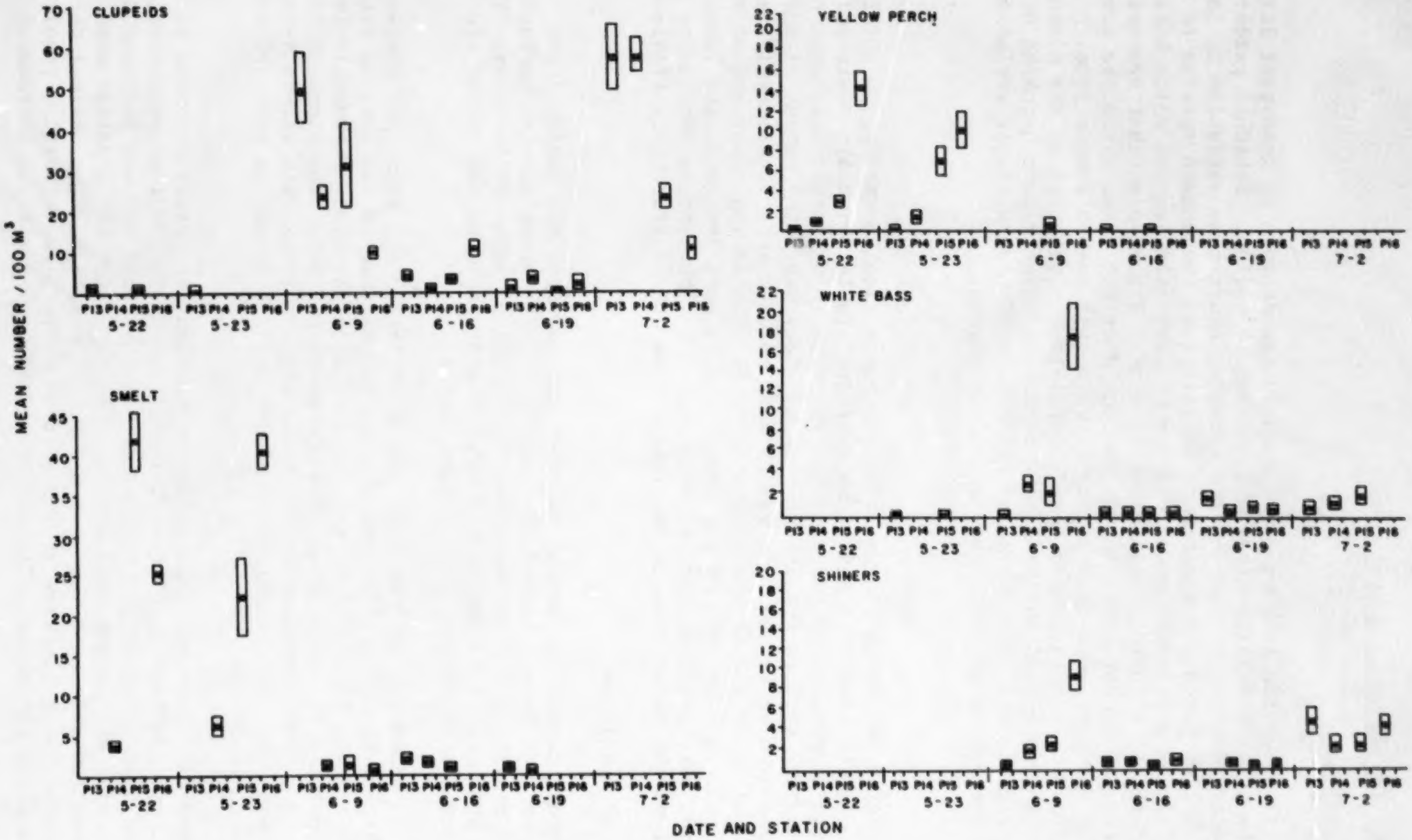


Figure 16. Mean number of larval fish captured (±SE) during the day (D) and night (N) for each depth stratum at station P17 (S = surface; MD = mid-depth; D = deepwater; and O = oblique tow).

Distributions in the Cooling System

Temporal--

Figure 17 shows the temporal variation in the capture of important larval taxa from the upper discharge canal and the intake region. Seasonal patterns repeatedly emerged in each year despite erratic, short-term variation in larval abundance. Yellow perch and smelt were the first of the common species to appear; their peak abundances were followed by carp-goldfish and white bass, and then, clupeids, shiners, and freshwater drum. The species that spawned earliest persisted as catchable larvae for the shortest time, while the progeny of later spawners were more likely to be caught over a longer time. Larvae of carp, white bass, and clupeids consistently appeared in the discharge canal before they appeared in the intake region; evidently some hatching occurred in the discharge canal. The larvae of channel catfish were almost exclusively captured in the discharge canal and the intake region.

Spatial--

Some species may hatch in the upper discharge canal according to total densities of larvae caught at different stations (Table 30; B26). Carp-goldfish, white bass and clupeids were captured consistently in the upper discharge canal in greater numbers than in the intake region. This was not apparent with the perch, shiners or drum larvae. Larvae of most species were consistently less abundant in the lower end of the discharge canal than in the upper end of the discharge canal. All but one of the abundant taxa were common in the lake. The exception, carp-goldfish larvae, were much more abundant in the river, as were several of the rarer taxa in the Ictaluridae and Centrarchidae (Table 30).

Variability of Results--

Even though consistent annual patterns emerged from the temporal and spatial patterns of larvae around the cooling system, great spatial variation only allowed statistical discrimination ($\alpha = 0.05$) of major differences. This variability appeared to be caused by "patchy" distributions and strong fluctuations in recruitment during the spawning season.

Figure 18 shows the influence of patchy variation for important species on the dates that spatial variation was minimum and maximum in the cooling system. Abundances tended to fluctuate at any one particular station, presumably in response to patches of larval fish moving through the lake ecosystem and the cooling system. Concentrations at the three lake stations, all within 4-km of each other, could be indistinguishable on one day and exceed an order of magnitude difference on another day.

The degree of variation determines the sampling intensity required to differentiate concentrations at different area stations for various permissable errors of the mean. Figure 19 illustrates how the variation was influenced by patchy distributions and temporal change. The variation was greatest when the mean catch was low and least when the mean catch was high. The minimal variation encountered for replicates at one station defined the situation requiring a minimum sampling intensity. The additional spatial variation introduced by

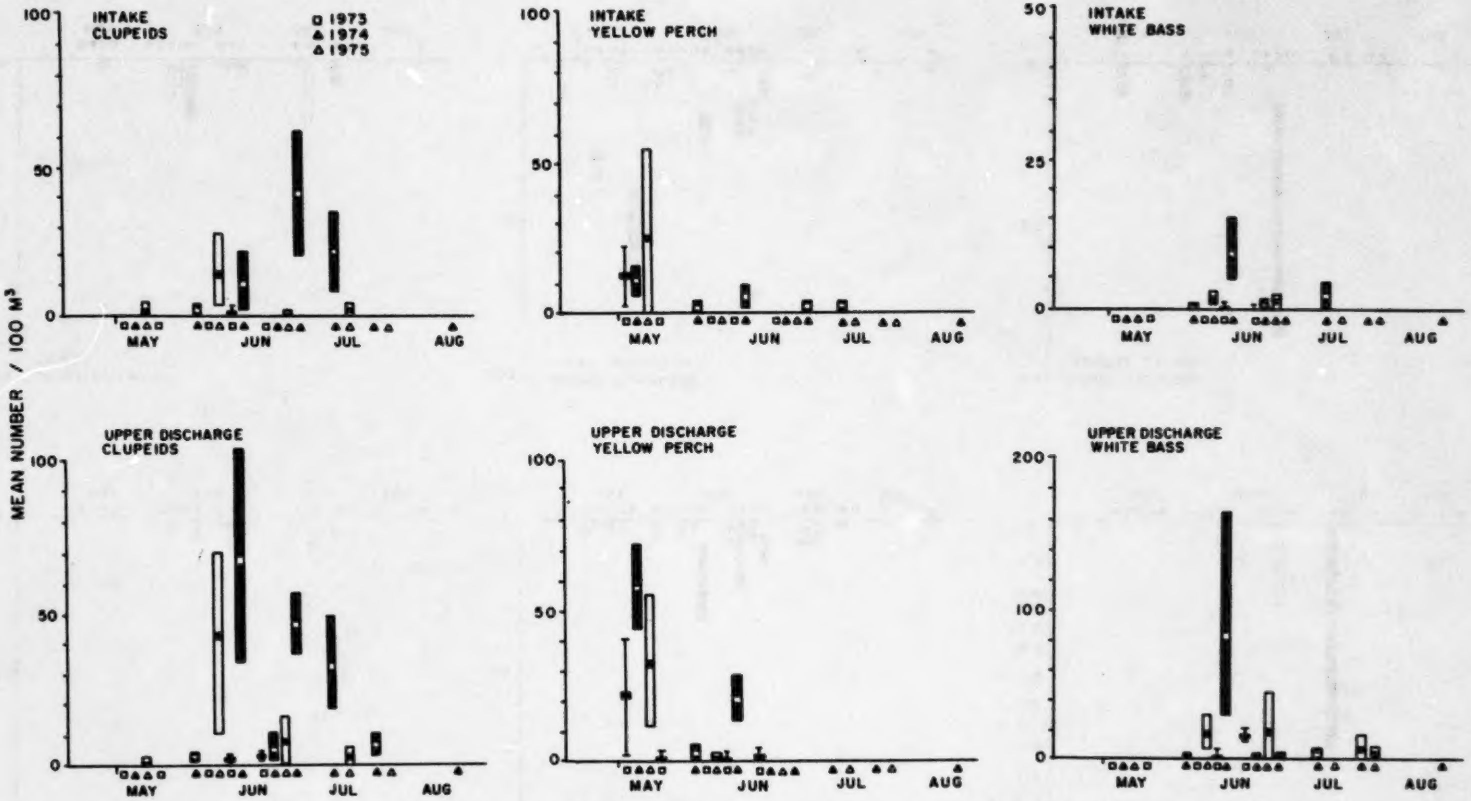


Figure 17. Seasonal variation in abundant species of larval fish in the intake region and upper discharge canal (mean ± 95% conf. int.)

(continued)

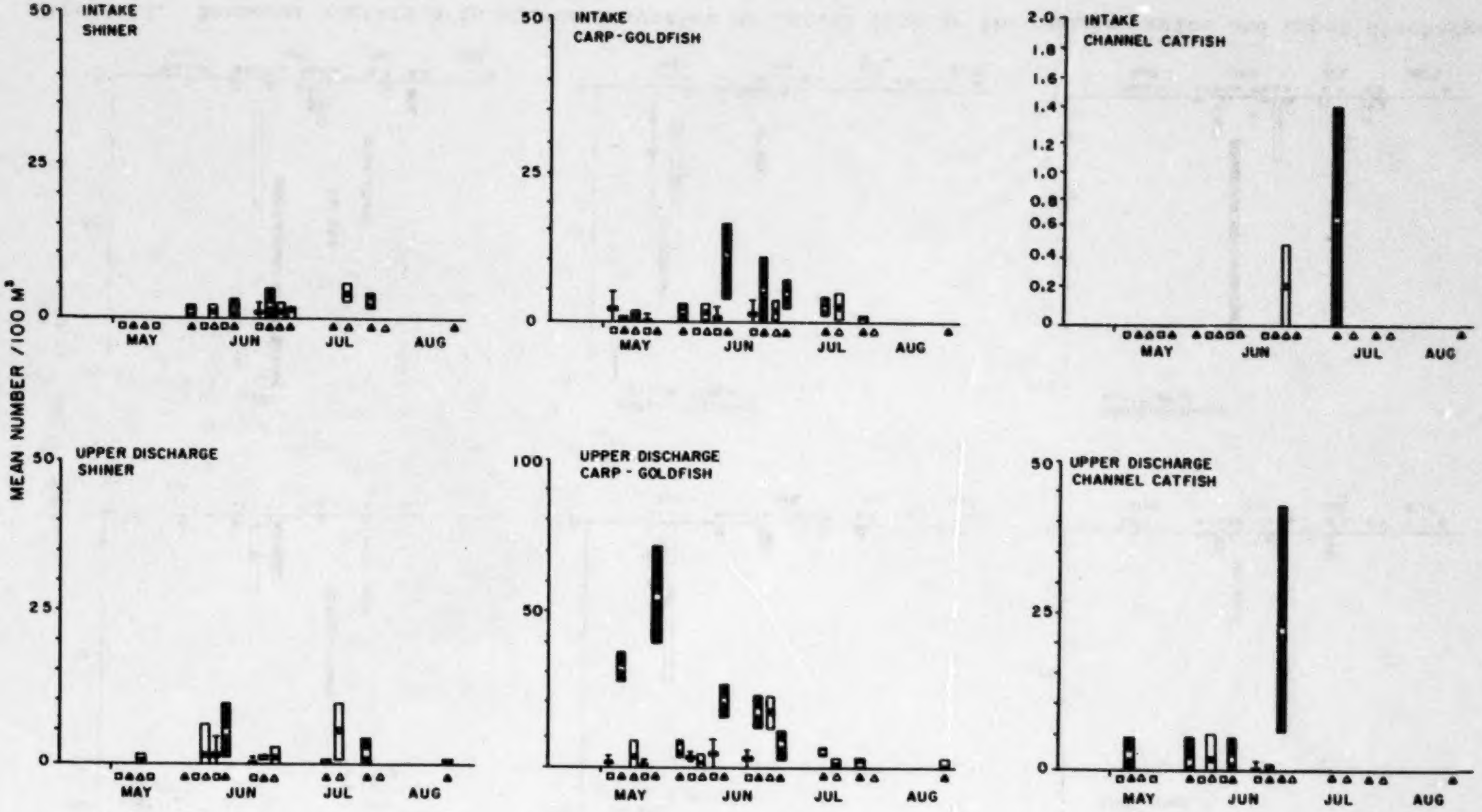


Figure 17 (continued).

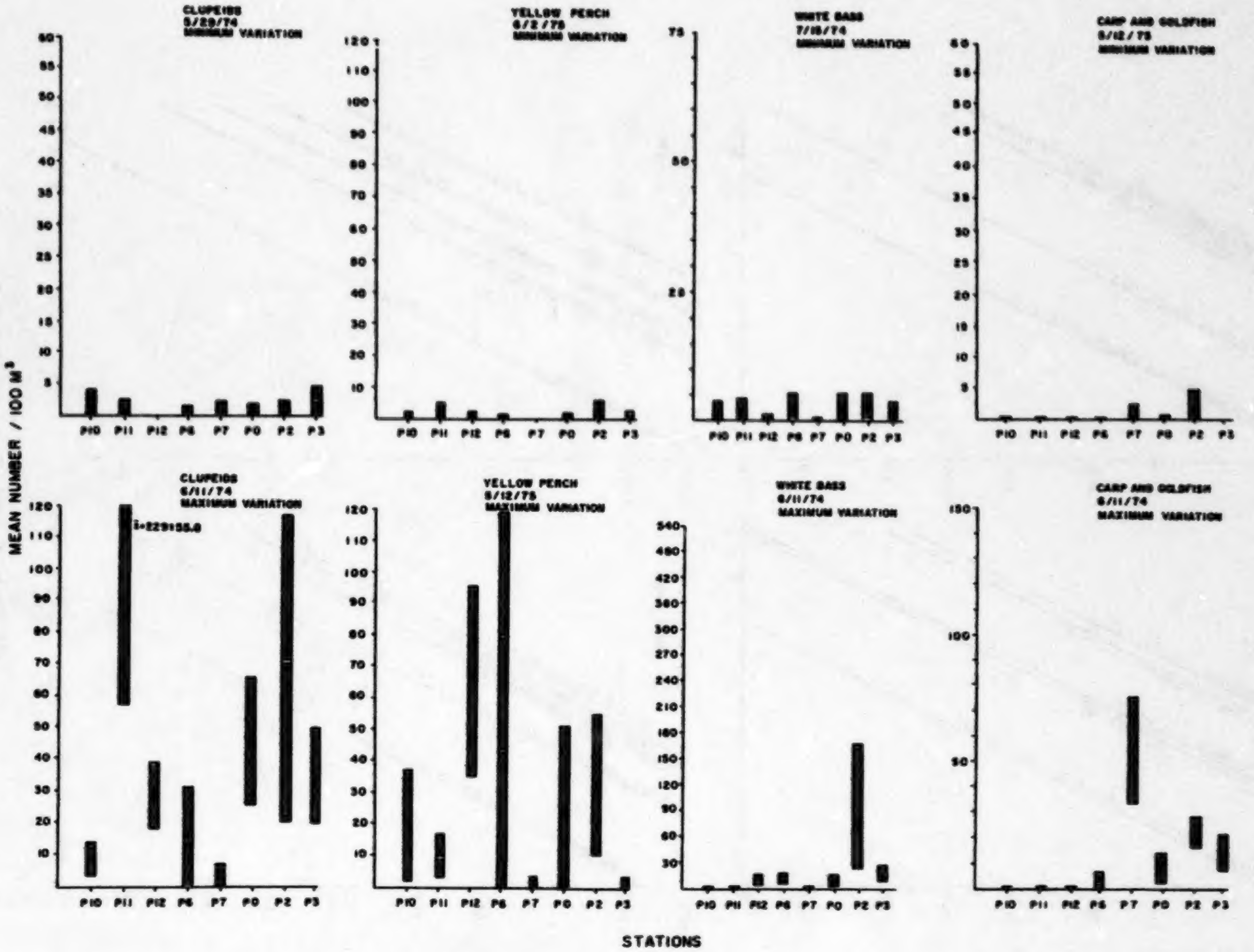


Figure 18. Minimum and maximum variation (± 95.1 conf. int.) in the catch of larval fish near the Monroe Power Plant.

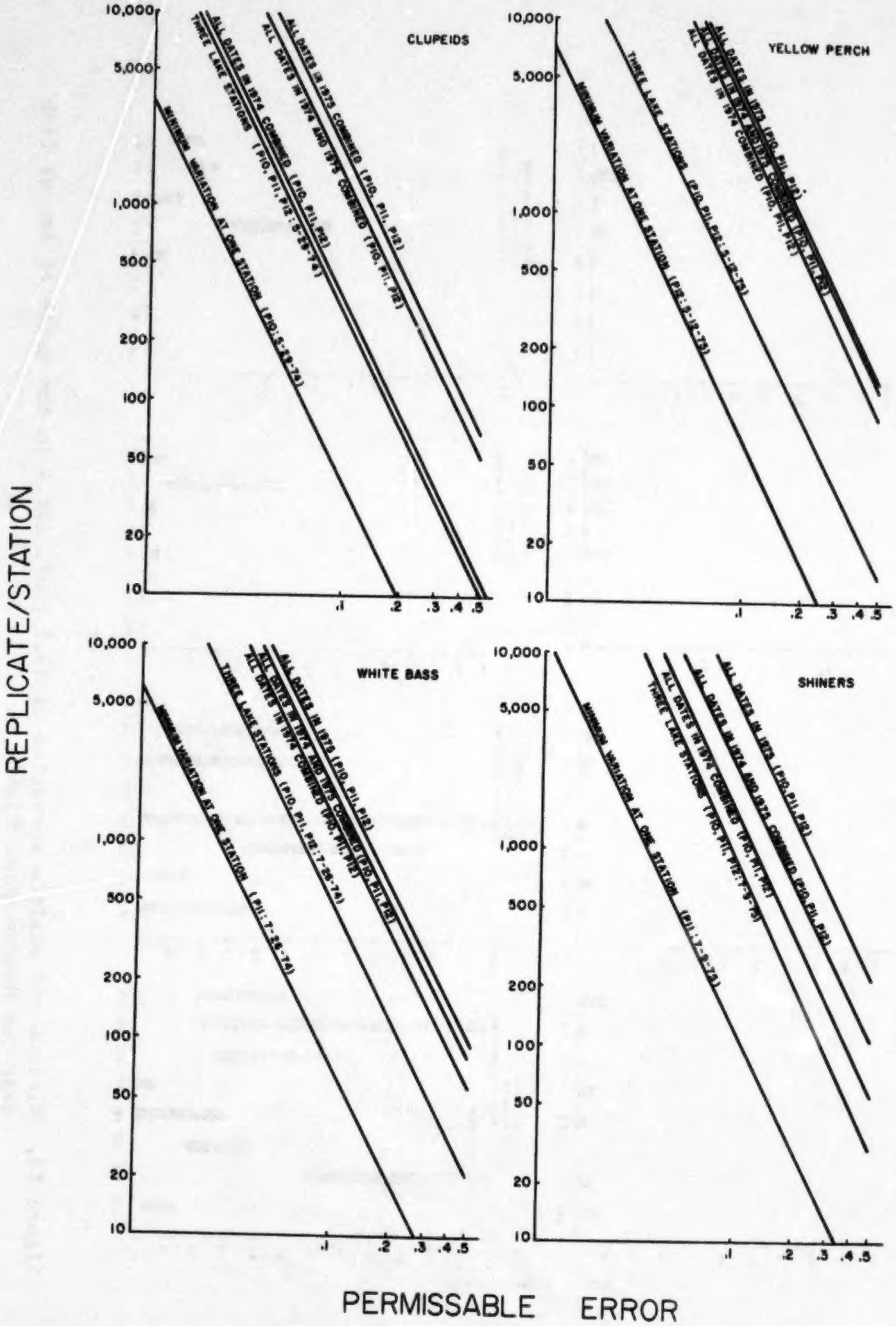


Figure 19. Sampling intensity required at various permissable errors of the mean.

sampling at two other nearby (2 to 4-km apart) stations on the same date required 6 to 10 times more intensive sampling to maintain the same permissable error. Based on the results from the three lake stations, the intensity of sampling on a particular date must be increased at least 100 times (depending on species and date) to reduce the permissable error from 50 percent to 10 percent of the mean with a 95 percent confidence interval. When variation at the three lake stations is included, the sampling intensity required increased from 10 to 1000 percent depending on the species and the year sampled.

There was considerable difference in the seasonal variability defined for two consecutive years; 1974 was less variable than 1975 for all important species. The long-term sampling intensity required over a sequence of annual studies to meet a specified error cannot be determined confidently with data from one year alone. To a great extent, the variability encountered was proportional to the mean larval concentration. The rare species encountered in the study would require an extraordinary sampling intensity to precisely estimate their population sizes.

Estimated Mortality

Substantial proportions of entrained larval fish may have died in the cooling system following condenser passage (Table 33). The percent killed at the intake station by capture technique and natural events varied with species. A relatively large proportion of white bass and carp larvae were dead in the intake canal while a relatively large proportion of yellow perch were alive. Following condenser passage, the proportion of dead larvae of all taxa captured increased from 20 to 80 percent. Considering the high probability that some larvae hatch in the discharge canal, these estimates of larval mortality caused by passage through the cooling system may be conservative. For example, yellow perch were among the least likely of the fish to hatch in the discharge canal and their death rate was among the highest. Consistently high variation (Table B31) interfered with the precise estimation of mortality. But these estimates, in combination with the consistently lower numbers observed in the lower discharge canal compared to the upper discharge canal, indicate that a large proportion of the larvae died as a consequence of condenser passage.

Foods

Comparisons of larvae of the same size obtained from light and dark times of the same day revealed no differences in mean size of foods, but in some species there seemed to be differences in the number of food items (Table 34). White bass and freshwater drum caught at night had a greater number of organisms in their stomachs than their daytime counterparts (Table 35). The stomach contents of yellow perch were similar for both time periods. Regardless of the time, Cyclops were the most numerous food organisms. Cladocerans may have been slightly more common in the larvae collected at night. Because light and dark times of only one date were compared, conclusions about the diurnal regularity of these differences are unwarranted. However, it seems like the species composition of foods remains similar even though the total numbers consumed may change.

TABLE 33. PRELIMINARY ESTIMATES OF MORTALITY IN THE COOLING SYSTEM AT THE MONROE POWER PLANT
(ratio of dead to total catch of alive and dead)

Species	Intake	Total Number Caught	Upper Discharge	Total Number Caught	Lower Discharge	Total Number Caught
Carp	0.09	20	0.27	8	low abundance	1
Yellow perch	0.20	40	0.72	5	low abundance	2
Clupeid	0.15	66	0.79	11	0.80	2
White bass	0.04	25	0.25	3	0.80	5
All larvae	0.16	176	0.73	29	0.59	10

TABLE 34. FOODS IN FISH LARVAE OF DIFFERENT LENGTHS CAPTURED NEAR THE MONROE POWER PLANT

	Smelt					White Bass					Perch					Gizzard Shad					
	8-11	11-14	14-17	17-32	Tot.	5-8	8-11	11-14	15-21	Tot.	5-7	7-9	9-11	11-15	Tot.	5-8	8-11	11-14	14-17	17-20	Tot.
Percent empty stomachs	60	50	66	12		60	16	0	0		56	4	0	0		63	13	6	16	20	
No. fish with food	4	4	1	7	16	7	15	8	6	36	6	25	7	8	46	6	13	18	10	4	51
Food Taxa																					
Cyclops																					
number	4	12	9	19	44	20	69	45	46	180	1	4	28	41	74	2	15	64	38	62	181
percent	67	71	100	54	68	71	97	98	92	90	4	3	88	93	31	14	47	59	81	82	69
Trophocyclops																					
number							1			1											
percent							1			.05											
Calanoids																					
number	2	1		12	15								3		3						
percent													9		1						
Other Copepods																					
number		2			2																
percent		12			3																

(continued)

TABLE 34 (continued).

	Smelt					White Bass					Perch					Gizzard Shad					
	8-11	11-14	14-17	17-32	Tot.	5-8	8-11	11-14	15-21	Tot.	5-7	7-9	9-11	11-15	Tot.	5-8	8-11	11-14	14-17	17-20	Tot.
Ceriodaphnia																					
number				1	1	5		3		8				3	3				3	8	11
percent				3	2	18		6		4				7	1				6	11	4
Diaphanosoma																					
number				1	1	3				3								1	1		
percent				3	2	11				2								1	2		
Chydorus																					
number												1			1			1			1
percent												1			0.3			1			0.3
Boomina																					
number		2			2													1	1	2	4
percent		12			3													1	2	3	0.7
Daphnia																					
number							1		4	5										2	2
percent							1		8	3										3	0.7
Other Cladocera																					
number				2									1		1					1	1
percent				6									3		0.3					1	0.3
Synchaeta																					
number												1			1		1	1	1	2	2
percent												1			0.3		3	1	2	3	0.7

(contined)

TABLE 34 (continued).

	Smelt					White Bass					Perch					Gizzard Shad					
	8-11	11-14	14-17	17-32	Tot.	5-8	8-11	11-14	15-21	Tot.	5-7	7-9	9-11	11-15	Tot.	5-8	8-11	11-14	14-17	17-20	Tot.
Trichocera																					
number																1				1	2
percent																7				1	0.7
Brachionus																					
number											12	42			54	2	3	4			9
percent											44	32			23	14	9	4			3
Keratella																					
number											2	31			33	1	1	5			7
percent											7	23			14	7	3	5			3
Actinastrum																					
number											2	1			3						
percent											7	1			1						
Other Rotifers																					
number											2	4			6	1	1	3	2		7
percent											7	3			2	7	3	3	4		3
Rotifer eggs																					
number											4	45			49	6	7	10	1		24
percent											15	34			21	43	22	9	2		9
Copepod eggs																					
number											4	2			6						
percent											15	2			2						

(continued)

TABLE 34 (continued).

	Smelt					White Bass					Perch					Gizzard Shad					
	8-11	11-14	14-17	17-32	Tot.	5-8	8-11	11-14	15-21	Tot.	5-7	7-9	9-11	11-15	Tot.	5-8	8-11	11-14	14-17	17-20	Tot.
Nauplii																					
number												2			2	1	2				3
percent												2			0.7	7	6				1
Protozoans																					
number																	2	18	1		21
percent																	6	17	2		8
Total																					

TABLE 35. STOMACH CONTENTS OF FISH LARVAE CAPTURED DAY AND NIGHT IN WESTERN LAKE ERIE

Fish	No. Food Items/Ten Fish							Food Size (mm) $\mu^3 x10^3$		
	Cyclops	Daphnia	Leptodora	Bosmina	Diaphanosoma	Ceriodaphnia	Calanoids	Mean Length	Mean Width	No. items per fish
Drum										
Day	53	2	--	2	--	--	--	1.70	0.59	0.53
Night	98	4	5	--	--	--	--	1.64	0.54	1.02
White Bass										
Day	68	5	1	2	--	1	4	1.41	0.47	0.79
Night	197	6	2	2	--	--	5	1.48	0.50	2.10
Perch										
Day	114	12	4	--	--	--	3	1.45	0.51	1.29
Night	97	13	17	3	1	1	--	1.54	0.55	1.13

The major apparent difference in the food habits of larvae compared to the older fish, described by Kenaga and Cole (1965; Appendix A), was size related. In older fish, chironomids were among the major food items and rotifers were scarce. In larvae, rotifers were common while chironomids were absent. *Leptodora kindtii* was an important food for older fish and some of the large postlarvae captured, but it was not found in the guts of small larvae.

SECTION 6

DISCUSSION

MIXING

The evaluation of mass transport of entrained plankton and nutrients at the Monroe Power Plant depended on estimates of mixing in the intake and the discharge plume. This was required to separate the effects of dilution from power plant operation. Two, fundamentally different sampling designs were available to choose from; the first was to follow and sample the same water mass as it passed through the cooling system and mixed with other water masses and the second was to sample specific points, almost simultaneously, using internal tracers as described in Spain and Andrews (1970) and Hem (1970).

The second approach was chosen because of tactical advantages. To follow and sample water mass moving through the cooling system over 24 to 48 hr required extraordinary effort. Following water masses requires frequent crew changes, tracking techniques are imperfect, sampling runs are excessively vulnerable to interruption by weather or mechanical failures, and diurnal cycles or meterological events may confound the results.

The major disadvantage of simultaneous sampling is the variability introduced by spatial variation in water masses, so-called patchy distributions. The tracer studies conducted in this research showed that patchy distributions could easily confound interpretation of differences observed among sampling stations on any specific date. The method required that the interpretation of results rest primarily on the consistency of annual mean differences which averaged out variability caused by patchy distributions. We assumed that spatial variation occurs randomly over the annual cycle. After being integrated as seasonal or annual means the data revealed consistent plant impacts that might otherwise be unidentified. From the standpoint of ecosystem dynamics, this approach is probably a more realistic assessment of overall impact than short-term sampling which could represent unique conditions that occur only for a brief time.

Based on this technique, the lake and river source waters differed mostly in quantity rather than quality of their chemical and biological constituents. The material composition was basically similar, but the river was richer in concentrations of carbon, nitrogen, and phosphorus and poorer in plankton. Oxygen concentrations and plankton diversity in the lake often exceeded that in the river. Virtually all of the river water was used for cooling while only a small fraction of the volume-flow through western Lake Erie (almost 1.5 percent) was circulated through the cooling system. Therefore, the planktonic community in the river was more vulnerable to entrainment than the lake community.

According to tracer studies of lake and river water masses, water sampled in the river channel was a product of lake and river mixing and; the estimated concentrations of dissolved and suspended matter reflected that mixing. River water diluted plankton concentrations in the lake water and the lake source diluted nutrient concentrations in the river water. Over the longrun, the degree of dilution depended mostly on river water. During high spring discharge, river water usually predominated in the intake while, in late summer, lake water predominated.

TEMPERATURE AND OXYGEN

The rapid and prolonged temperature change caused by once-through cooling may have been one of the causal mechanisms associated with some of the observed changes in community structure and function. The mean annual temperature elevation varied only from about 6 to 9°C, but day to day variations ranged from 0 to 17°C. This wide variation undoubtedly could have effected a wide variation in community response. But the mean elevation, maximum elevation, and even the stability of elevation observed at Monroe were not atypical for steam-electric plants (Contant, 1971). Maximum summer temperatures may be of particular concern because many warm water, species appear to reach their upper thermal tolerance limits between 30 to 35°C (Strangenberg and Pawlacyzk, 1960; Massengill, 1976; Marcy, 1971). Those temperatures could occur at the Monroe Power Plant about 25 percent of the year in June to September, when it operates with a 10°C elevation of the cooling water.

Following condenser passage during summer, the oxygen concentration tended to increase because concentrations were usually depressed in the source waters. At that time of year, the partial pressure of oxygen was influenced by intense primary productivity as well as community respiration and change in temperature. During the cooler months when community metabolism was relatively low, cooling water generally became supersaturated because of temperature change alone. Other researchers have warned that gas supersaturation, especially from nitrogen, could cause damage to the fish but Cole (1976) reported that no such effects were observed at the Monroe Power Plant. Nitrogen gas concentrations were not measured but, based on winter observations made at other sites (Adair and Haines, 1974), the percent saturation of oxygen probably reflected the percent saturation of nitrogen near the condenser. At Monroe, that would most commonly be 110 to 120 percent of saturation.

NUTRIENTS AND PRIMARY PRODUCERS

Changes in material concentrations that resembled changes in the tracers were assumed to be caused by mixing alone. Deviations from tracer projections indicated material losses or gains which could not be explained by mixing alone. The annual mean concentrations of nutrients and primary producers consistantly deviated from the anticipated mixed concentrations and revealed relatively minor but real changes in water quality which could not be consistently identified with statistical confidence because of high background, spatial variation.

Ammonia may have been rapidly released from protein decomposition before water reached the upper discharge canal; but that was the only recognizable nutrient change in water at the upper end of the discharge canal. Mean annual gross primary productivity at the upper end of the discharge canal remained unchanged or was depressed. Since cool weather productivities were, in most cases, too low to identify differences, the observed depressions were generated mostly at temperatures above 15 to 20°C. Morgan and Stross (1969), Hamilton et al. (1970), and Warinner and Brehmer (1966) all found similar depressions at warmer temperatures.

The annual mean community respiration about doubled by the time water reached the upper discharge canal. With a mean annual temperature rise of 8°C. It appeared as if the general relationship between respiration and temperature approximated the Q_{10} rule.

Even though the P/R ratios dropped sharply in the upper discharge canal, they remained high enough to produce more organic material than was consumed in the cooling system. Particulate organic carbon increased, presumably from photosynthetically fixed organics in the discharge water, as discharge water passed back to the lake. Gains of particulate carbon were accompanied by consistant increases in algal abundance, a decline in the inorganic nitrogen and a complimentary increase in organic nitrogen. Phosphorus concentrations could have been drawn upon for photosynthesis, but the amount required was so slight that the technique could not identify the changes caused by phytoplankton uptake if it existed. Dissolved inorganic carbon declined, possibly from photosynthetic demand, CO_2 losses to the atmosphere or from the precipitation of carbonates.

By the time the cooling water reached the lower discharge canal, from 6 to 12 hours later the mean P/R ratio and the mean ratio of particulate to dissolved organic carbon had increased slightly. The P/R ratio still remained nearly half that in the intake waters, indicating that the water in the lower discharge canal continued to be less autotrophic than the source waters. Respiration remained almost the same while gross primary productivity increased, but not enough to completely make up for the depression started in the upper discharge canal.

In the plume, particulate organic carbon, and organic nitrogen increased slightly above the expected concentrations while dissolved organic-nitrogen, inorganic nitrogen, inorganic carbon and total phosphorus all declined by 15 to 25 percent. Carbonates and phosphates seemed to precipitate as the plume mixed with the receiving waters. Inorganic nitrogen and carbon may have settled with particulate organics or escaped from the water as ammonia, nitrogen gas and carbon dioxide. The latter explanation seemed to be the the most reasonable of the two. Suspended solids declined only about as suspected by dilution at the plume edge and there was no indication that much particulate matter settled to the bottom over the shallow shoal.

In spite of a prolonged 6 to 12 hour exposure to elevated temperature, the primary productivity began to increase before the cooling water reached the lake. Even after the cooling water had mixed with lake water, the primary productivity continued at an intensity higher than expected from mixing. These results differed from those of Morgan and Stross (1969) who concluded that photosynthetic depression persisted until the water had cooled to ambient temperatures.

Although the changes were slight, the consistently measured increases in algal abundance and particulate organic carbon indicated that photosynthetic biomass increased as water passed through the cooling system and net production continued to remain higher than predicted by the mixing of the thermal plume with ambient waters. Nutritional changes in the mixing waters of higher algal biomass may have caused slightly higher productivities at the plume edge than in nearly ambient waters. Light limitations, as effected by changing concentrations of suspended solids, appeared to be unimportant. No consistant relationship appeared between distributions of productivity and concentrations of suspended solids in the cooling system.

Community respiration like gross productivity, was higher than predicted by mixing in the plume and the P/R ratios returned to values like those at the intake. Although there was a small gain in algal standing crop and, possibly, slight temporary changes that favored green and blue-green algae, there was little net change in the organic carbon transported to the lake because dissolved carbon had declined before the cooling water mixed with the lake water. The water leaving the plume probably had a potential oxygen demand similar to water entering the intake. In fact, water quality may have improve slightly because phosphorus, and nitrogen concentrations also declined before the cooling water mixed into the lake water. The same patterns of community metabolism consistently materialized in the discharge water regardless of chlorine application schedules. These observations, along with the fact that chlorination occurred no more than 33 percent of the time, indicated chlorine affected planktonic community metabolism very little.

Periphyton rates of accumulation were extremely variable, but trends indicated that the upper discharge canal rates were less than at other sites including the lower discharge canal where temperatures were similar. Chlorine may have inhibited periphytic growth in the upper discharge canal even though it did not seem to be primarily responsible for phytoplanktonic responses. It is also possible that periphytic organisms were not entirely unaffected by mechanical stress or thermal shock. The colonizing capacity of organisms adrift in the cooling water might have been temporarily incapacitated by condenser passage. Whatever the effect on periphyton, it did not seem to persist far down the discharge canal or in the thermal plume.

Although subtle but real changes in community metabolism appeared to be caused by entrainment, community structure changed little. The diversity of phytoplankton in the cooling system appeared to be regulated almost entirely by the mix of river and lake source waters. Although slight population shifts appeared in certain species, they had no recognizable impact on diversity estimates. Given the rapid regeneration rates of phytoplankton and the size of Lake Erie, the entrainment effect on the phytoplankton of western Lake Erie was a transitory disturbance superimposed on an aquatic community that is prone to erratic, relatively massive, meterological disturbances (Chandler, 1944). Based on basin-wide estimates of phytoplankton distributions (Hartley and Potos, 1971) and flow through the western basin, even complete destruction of all phytoplankton entrained at Monroe would amount to less than 1 to 2 percent of the total in the western basin. But more important in western Lake Erie is the threat of increased oxygen demand generated by eutrophication. If anything, the thermal discharge accelerates the recovery of nutrient enriched waters entering the basin via the Raisin River without locally aggravating oxygen depletion rates. Even though this is a desirable reduction of nutrient loading to the basin it is a relatively minor deduction, at most 1 percent of the total estimated (IJC, 1969) from all tributaries.

One negative impact observed was the apparent effect of erosion from the cooling system. If this erosion rate were maintained over the next 35 years, there could be a net export of sediments equivalent to 1-m deep by 1 km^2 of lake bottom off the discharge canal. Of course, much of this material would be dispersed by lake currents over a large part of the western basin. If it were evenly dispersed over the entire basin, it would accumulate about 0.01 mm/year. This amount is equivalent to about 2 percent of the estimated sediment load (IJC, 1969) entering Lake Erie via the Maumee River.

ZOOPLANKTON

The mean annual distributions of all the major taxonomic groups of zooplankton indicated consistent entrainment impacts. A mean annual average of about 40 percent of all zooplankton disappeared from the water column somewhere between the intake and the sampling location in upper discharge canal. The effect at the Monroe Plant was consistent for all of the major taxa present regardless of size or behavioral differences. Beck and Miller (1974) and Carpenter (1974) reported even higher losses caused by mechanical damage. Although declines may be expected for zooplankton abundance downstream from a power plant, other field studies usually identify little recognizable impact in the receiving water (Davies and Jensen, 1974).

The specific cause of the impact at the Monroe Power Plant is perlexing. It is unlikely that the depression is an artifact caused by incorrect estimates of the mixing rates of river and lake water. It could have been caused by sampling error if the contribution of river water had been overestimated. But such a sampling artifact should be reflected in the abundance ratios of specific taxa. For example, rotifers were relatively more abundant than copepods in the river water compared to lake water. If the estimated river contribution were too high, then rotifer densities should have decreased less than copepod densities. Just the opposite appeared in the data. According to trace data, the river-water contribution, if anything, was underestimated.

Whatever depressed zooplankton density did so before the water reached the upstream station in the discharge canal. After that, densities remained fairly constant in the discharge canal. Before reaching the discharge canal, the plankton passed through the pumps, then the condensers at about 2 m/sec and finally into the concrete overflow canal which carried them at about 0.75 m/sec to the upper discharge canal within 20 minutes of the condenser passage. Potential fish predators have never been sampled in the overflow canal, but water velocities seemed too high and the canal too short to foster high fish abundances like those in the discharge canal (Cole, 1976).

Chlorine was not applied in the afternoon, but the differences in population density changes between that time and the chlorination times was not enough to implicate chlorine as a primary factor. Even if chlorine were killing animals, it would not completely destroy the bodies of individual zooplankters.

Dead, dying, or "shocked" animals could have settled to the bottom from the sampled water column, although this was unlikely in the rapidly flowing water of the overflow canal. Zooplankton may have settled from the upper discharge canal soon after water emptied into it from the overflow canal. Velocities in the discharge canal averaged less than 0.15 m/sec and may have been much less than that near the bottom. Some of the animals may have moved toward the bottom as soon as they passed into the upper discharge canal. McLaren (1963) and Gehrs (1974) found that at least certain species swam toward bottom when they were exposed to higher temperatures. Many of the zooplankters may have moved or settled to depths below those that were sampled, causing an apparent loss only.

Other slight changes in the abundance and size distribution of zooplankton may have occurred after the plankton drifted downstream from the upper discharge canal. Although the density increased only slightly, if at all, as the plankton passed down the discharge canal, the mean size of zooplankton, particularly cladocerans, appeared to decrease. These size changes in cladocerans may have occurred because larger animals, more than smaller ones, were eaten, settled out, or emigrated from the water column, or there was some combination of size related recruitment and mortality. Among copepods, the mean size of adults and nauplii changed without constant trend during passage. On the other hand, the mean size of rotifers seemed to increase as if in response to some competitive release.

Regeneration probably contributed little to the decreased mean size that was witnessed during passage through the discharge canal, but the densities seemed to increase slightly as the water passed through the cooling system. A very small change could have been caused by recruitment. Under optimal conditions, with a life expectancy of 2 weeks and a mean fecundity/individual of about 10 young (Geiling and Cambell, 1972; Eckstein, 1964; and Munro, 1974) the density of copepods and claderans could have increased only 2 to 3 percent in 6 to 12 hours. Vertical profiles of zooplankton abundance indicated that many of the cladocerans and copepods recovered their ability to orient to depth related gradients by moving toward bottom within a few hours of the time that they passed through the condenser.

At least some of these larger organisms could have moved far enough away from the surface to entirely avoid capture. The mean size of cladocerans, in particular, seemed to decrease as the plankton passed down the canal, perhaps because larger animals settled or moved out of the water column or because they were eaten. Kenag and Cole (1975) indicated that certain fish species caught in the vicinity of the power plant tended to be size-selective feeders. Kelly and Cole (1976) also found parallel size changes in benthic organisms inhabiting the discharge canal. Cole (1976) reported that fish densities in the discharge canal usually exceeded those in the nearby lake, so the depressed sizes may have reflected the effect of intense predation.

If a size-related selection process was operating in the cooling system, it had no recognizable impact on the diversity. Diversity indices have been promoted as one integrative means for identifying community-wide influences of man-caused perturbations (Wilhm and Dorris, 1968). But, none of the diversity estimates made during this study indicate that passage through the cooling system had any consistent impact on community structure.

The chloride tracer indicated that little cooling water was recycled by power-plant operation even though the wind frequently forced the plume waters northward toward the intake. Neither samples of zooplankton or chloride, taken over two to three-day periods, revealed any trends in changing concentration that would suggest a cumulative effect from recycling. The dilution of discharge waters by the receiving waters effectively diminished any recognizable entrainment impact at the plume edges.

The abundance of zooplankton in the cooling system followed patterns similar to adjacent parts of western Lake Erie (Cole, 1976) during the same years of study. None of the entrainment effects persisted beyond the plume into western Lake Erie.

Based on the rates used during this study, the power plant pumped about 0.005 km^3/day. In the study reported by Cole (1976), zooplankton were sampled along the central axis of a rectangular coastal area that was about 15-km x 4-km and averaged 5-m deep. The volume of that area comprised the equivalent of 0.3 km^3 of cooling water. Assuming no mixing with other lake water, it would take about 2 months to move all of that water through the cooling system. Even if all zooplankters were killed in passage, the residual populations within that relatively small part (less than 2%) of the western basin would be capable of turning over 2 to 4 times during the summer months based on a 2 to 4 week life expectancy of most zooplankton. The western basin is well mixed and the calculated replacement rate for water in the whole basin is also about 2 months. There could be little entrainment impact of consequence on total zooplankton abundance in such a large dynamic system even though entrainment may have temporarily disoriented animals, increased their vulnerability to predation and, perhaps, even destroyed up to 50 percent of all entrained animals. However, one species of zooplankton, Leptodora kindtii, may have been exceptionally affected because of its relatively large size and relatively slow regeneration rates.

FOODS OF FISH

Entrainment could indirectly disrupt trophic relationships between important fish populations and their prey. Much of the economic and ecological value of some invertebrates and small fish manifest in their importance as fish food. One major conclusion has emerged from our work on fish foods; the size of the consumed food is related to fish size. The smallest fish larvae used rotifers, copepod nauplii and other small, planktonic organisms. Larger larvae depended more on larger copepods and cladocera. Juvenile fish, over 30-mm long, ate few rotifers and appeared to select the largest food items available to them; the large cladoceran, L. kindtii, and two genera of midge larvae, Procladius and Chironomus.

A continuously abundant and diverse assemblage of small zooplanktonic foods appeared to be available to small fishes from April to October, but larger food species appeared less diverse. Among potential zooplankton foods, less than 0.2 mm long, there were 23 species of small rotifers and the nauplii of 10 copepod species. In a slightly larger group of food species, ranging from 0.5 to 3 mm long, there were 10 species of juvenile and adult copepods and 5 species of cladocerans. Only one zooplanktonic invertebrate commonly exceeded 1 cm, L. kindtii.

Other large food organisms were found among the twenty-six taxa of benthic macroinvertebrates encountered in the study area (Kelly and Cole, 1976). Half of these species were tubificids, a group which was not found in the stomachs of any fish examined (Kenaga and Cole, 1975; Appendix A). These organisms seemed not to be available as a food source. The remaining benthic species were mostly arthropods and mollusks, of which three genera of midges comprised 98 percent (Kelly and Cole, 1976). The stomachs of some of the largest fish also had fish remains (Kenega and Cole, 1976).

Among the carnivorous fish over 30-mm long, 60 to 95 percent of the food volume was comprised of L. kindtii, Chironomus and Procladius; all over 1-cm long. Large cladocerans and copepods made up most of the remaining stomach contents. The larger species were relatively rare in the study area but they were selcted as food much more often than the common but smaller species. Both LeBrasseur (1969) and Brooks (1968) found that organisms below a given size were ignored when larger alternative organisms were present.

Lake Erie has suffered from increased siltation, oxygen demand, contamination with toxic materials and parallel changes in the species composition of the benthic macroinvertebrates (Regier and Hartman, 1973). Many of the larger species of arthropods have radically declined in abundance while tubifids have increased (Carr and Hiltunen, 1965), leaving a monotonous benthic community dominated by midges and tubificids. Since tubificids seem not to be consumed by fish, the forage base has become restricted to fewer species than in the past. Juvenile and adult fish may now rely more continuously on zooplankters for food, especially L. kindtii. The change in the food resource may have intensified competitive interactions among the different sizes of fish enough to cause some decline in the growth of older age groups.

To some unidentified extent, condenser passage may, at least locally, depress the diversity of food sizes by selectively killing larger organisms (McNaught, 1972). Our preliminary studies of plankton mortality, like those reported by Massingill (1976) for the Connecticut River, indicate that L. kindii is relatively vulnerable to condenser passage compared to smaller zooplankters. Massengill (1976) also indicated that entrained midges suffered high mortalities. The relatively large larval fish also seem prone to high mortality from mechanical damage (Marcy, 1971, 1973 and 1976).

Because Leptodora kindii were relatively rare in the samples, any power plant impacts on their abundance could have been missed. Conclusions reached for zooplankton populations in general probably do not apply specifically to

L. kindii. Destruction of this important forage species could have a local impact on the growth of some fish species. It is an exceptionally important organism that deserves more attention than it has received.

LARVAL FISH SAMPLING

Techniques

The entrainment of larval fish may best be mitigated by appropriately locating intakes during plant construction. Useful information for appropriate plant siting, or the evaluation of an operating plant's effect, requires a precise, representative, cost-effective assessment of larval fish distributions. The comparability of sampling results from biologically and physically diverse environments, must be a paramount concern for an objective inventory. Both fish distributions and sampling techniques may be independently influenced by the physical aspect of the environment; mostly by variations in depth current velocity, turbulence, bottom configuration, and water clarity. The primary objective of our technique comparisons was to establish the relative effectiveness of some commonly applied techniques in the open water of western Lake Erie. We concentrated on use of open, 1-m, plankton nets because of their many practical advantages. The results of these technique comparisons may be applicable to any comparable, turbid, shallow lake or reservoir populated with similar fish species.

The 1-m, plankton net has operational advantages on small vessels that favor its use over small pumps or high-speed nets. Water can be processed more rapidly and it is relatively easy to manipulate the plankton net for depth-discrete or depth integrated sampling. The high-speed sampler is particularly impractical in relatively shallow, shorezone areas. In this study, pumping took 20 times as long as tow-netting to process the same amount of water processed by to the 1-m net. Both pumping and high-speed netting damaged more larvae. But, most importantly, the 1-m net consistantly was at least as effective as the Kenco Pump and the high-speed plankton sampler. Using another pump type for zooplankton, Icanberry and Richardson (1972) similarly found no difference between the pump and a 150-μ net.

With the 1-m net, the mesh-size time of day, and depth of tow all profoundly influenced the capture rate of larvae. These studies indicated that the most effective, daytime sampling would be a combination of bottom-sled and oblique tows. During the day, oblique tows alone cannot account for the sharply stratified, high concentration of larvae at the bottom because the net cannot be reliably drawn close to the bottom except in very shallow water. Without a bottom-sled, daytime tow-netting is more likely to catch larvae in shallow water than in deeper water. Above the dense larval layer near bottom, the vertical distribution of larvae revealed no consistent, depth-related patterns. Yet, enough differences occur among the discrete depths sampled to warrant pooling the variation by sampling with oblique tows.

The nighttime sampling effort yielded more larvae then the daytime effort. This is a commonly described phenomenon in a variety of environments (Miller et al., 1963; Clutter and Anraku, 1968; Noble, 1970; Faber, 1967; and Marcy, 1973). From 2 to 50 times more larvae were captured at night than day in oblique tows. The estimated nighttime catch per square meter of surface, without the bottom sled, averaged roughly similar to the daytime estimate with the bottom sled. This similarity in estimated day and night densities per unit of surface suggests that larvae were not concentrated near the bottom at night like they were during the day. The cumbersome sled may be an unnecessary addition to oblique sampling after dark. The nighttime variation among the station replicates was less than the daytime variation. As long as navigation is not too time consuming, night sampling probably will yield more information than day sampling.

Oblique, night sampling was more efficient than stratified night sampling. Although species like perch and smelt tended to concentrate in the lower strata, the differences in nighttime vertical distributions above the bottom were not nearly as great as vertical differences in current velocities. Depth related variations in water velocity were much more likely to influence the determination of the nighttime changes in larval fish distributions than the relatively minor vertical variations in larval densities. Studies of wind-generated movements in various environments indicated that velocities can change an order of magnitude within a few meters of the surface (Hutchinson, 1957) and this appeared to be substantiated by our studies (Hartley _et al_., 1966) in the vicinity of the Monroe Power Plant.

Hypothetically, both mesh size and tow length may influence the catch rate of plankton nets. Wichstead (1963) and Tranter (1963) found that different mesh sizes affected the yield of zooplankton because of the animals size distribution, the net filtration efficiency and the rate of net clogging with suspended matter. In this study, all nets larger than 363 μ captured far fewer prolarvae than the 363 μ nets. Whereas the 1000 μ mesh was unsuitable for all sampling, the 571 μ and 760 μ nets appeared to catch postlarvae about as effectively as the 363 μ nets. Where there are strong spatial and temporal variations in the suspended solids, the optimum net size will vary accordingly. Either a "compromise" mesh size needs to be selected or the mesh size will have to be adjusted to suit the specific conditions. In the study area, the compromise mesh size for all larval sizes appeared to be between 361 μ and 571 μ. For postlarvae alone, the compromise mesh size may be 760 μ.

The length of a tow that can be made without affecting the capture rate may depend on the mesh size because the amount of clogging from suspended matter depends on the time towed (Vanucci, 1968). The results of towing 571-μ nets from 1 to 5 minutes indicated no differences in capture rates for any towing times under the conditions that were sampled in Lake Erie. The patchiness in larval fish distributions may influence the choices of a tow length if the filtering efficiency is not greatly affected by the towing time. Noble (1970) noted that short tow times may enable an increased number of samples and decreases the variability which may be introduced by longer tows. This is most likely to be true when the larvae are grouped in relatively large patches or are not at all clumped in their distributions. On the other hand, Wiebe (1971) thought he gained precision by lengthening tows whenever larvae formed small patches because there was a greater probability of sampling a similar number of patches.

In our studies, the length of tow between 1 and 5 minutes did not affect the catch rate or variability of catch even though the variability among replicates reached a 300 percent coefficient of variation. The Lake Erie distributions appear to be less variable than those described by Wiebe (1971). Considering the information return per unit effort for estimates of abundant larvae on western Lake Erie, shorter 1- to 2-min tows should yield more than longer tows because a greater number of samples can be gained within the total time available for study. If rare species are to become the target, the tow length may have to be elongated to avoid too many empty tows or individual tows may be pooled for analyses. In situations where densities are unknown, the latter approach allows more flexibility.

An efficient approach to defining horizontal distributional variations near shore would be to sample at night with 1 to 2-min oblique tows. Even though night navigation can be difficult and night sampling is more time-consuming than day sampling, greater information appears to be gained from night sampling. The size of the water body, distance from shore and availability of lighted landmarks and buoys will help to determine the relative effectiveness of night sampling.

Distributions

The kinds of distributions exhibited by different fish species not only helps to clarify their relative vulnerability to intake entrainment but also aids in choosing a suitable sampling design to determine their abundance. The combination of environmental heterogeneity and behavioral attributes of the larvae often causes non-random, "patchy" (Cushing, 1961), "clumped" (Wiebe, 1971), "aggregated" (Barnes and Marshall, 1951), or "overdispersed" (Cassie, 1959) distributions which are usually described or approximated by the negative binomial (Taylor, 1953) or Poisson-log-normal distribution. These distributional variants have been hypothesized to originate from water discontinuities and heterogeneity arising from weather phenomena and tributary hydrodynamics or interspecific and intraspecific behavioral patterns (Cassie, 1962; Saville, 1965; Barnes and Marshall, 1951; and Wiebe, 1971). In western Lake Erie, both wind and tributaries could influence the patchiness of larval fish distributions. The relatively great sample variation among replicates at a station many indicate that the larvae are concentrated in "swarms" of relatively small volume (less than a few meters in diameter) like those described in Barnes and Marshall (1951). However, the average concentration within groups of swarms at different stations could vary by an order of magnitude within a few kilometers, just as Silliman (1946) found in the distributions of pilchard, Sardinops caerula, eggs. The distributions of most larval species frequently seemed to occur at patches over 100-m long (length of a 3-min tow). It was not possible to tell whether gradual density gradations or large, discontinuous patches occurred in the study area. Therefore, the upper size limits of any patches present were unknown.

The configuration of these patchy distributions may be at least partly dependent on the fluctuations of tributary mixing with lake water, wind-generated vascillations, and larval locomotion. Both Bishai (1960) and Saville (1965) thought that current was the most important determinant of larval fish distribution in oceanic environments. In western Lake Erie, currents are controlled mostly by the wind and the Detroit River. Prevailing southerly winds tend to maintain a clockwise gyre off the mouth of the Maumee River in the southwestern corner of the lake (IJC, 1976); therefore, the prevailing currents move a combination of Maumee and Detroit River water northward along the shore past the power plant intake. Several kilometers off shore, the water is derived almost entirely from the Detroit River (Hartley et al., 1966).

The results from the sampling transect, which extended deeply into Detroit River waters, suggest that, on the dates sampled, dense concentrations of yellow perch, white bass and smelt larvae entered the western basin with water from the Detroit River. The shiners followed no clear density gradient associated with the distance from shore, but the clupeids and freshwater drum were most abundant near shore on those dates. They may have hatched near the power plant or drifted northward from the Maumee Bay region. On the otherhand, with the few dates sampled the apparent distributions of these larvae may have arisen from a fortuitous combination of relatively abnormal conditions. Larval groups, including catfishes, sunfishes, and carp-goldfish, were common in the river but not in the lake. These species require marshy or protected shoreline environments for successful spawning and most river larvae probably came from marsh overflow or protected river edges. No simple generality appears to apply to the distributions of all larval fish species in the vicinity of the Monroe Power Plant.

Neither are the larvae all distributed alike in the water column, although both pro- and post-larvae of abundant species seem able to move vertically, apparently in response to changing light intensity. Nighttime concentrations of pro- and post-larvae in the water colume were much greater than daytime concentrations above the bottom, but they were similar (although variable) when daytime bottom tows were included in the comparison. Larvae may have differentially avoided the net during these tow times, but vertical movement seems to be a more plausible explanation. Although slower prolarvae are more likely to be vulnerable to capture during the day than the faster postlarvae, there was little evidence of difference. Also, the high-speed plankton sampler should have been consistently more effective than a tow net if net avoidance had been very important. This diurnal vertical migration between the slowly moving bottom waters and the relatively rapidly moving surface waters strongly affects the probability that discretely-located larvae will be carried to an intake.

Some subtle differences occurred in the vertical distribution of the abundant species. Most members of all species remained close to the bottom during the day and mostly in the lower half of the water column at night. Freshwater drum larvae seemed to move toward the bottom almost immediately after hatching from their floating eggs, and remained particularly close to the bottom during the day. Yellow perch, smelt, and white bass also tended to avoid surface waters, at least more so than the clupeids, which were the least likely of all the species sampled to avoid the relatively rapid currents near the surface. Therefore, a larger proportion of the clupeids could have been carried greater horizontal distances away from their points of origin than other species. Relatively small proportions of the demersal larvae were likely to be carried long distances away from their hatching sites.

Entrainment Susceptability

Counting entrained animals alone (Table 36) cannot reveal what impact a once-through cooling system has on populations in the source waters. Data also should be gathered in the source waters as well as the cooling system. These results, similar to Marcy's (1971; 1973), point out that entrainment probably kills larvae at high rates. But, the sampling intensity required to identify an entrainment effect on lake populations depends on what proportion of the population can be sacrificed to plant operation without endangering the resource value of the lake.

It is possible, from the data presented here, to tentatively estimate the vulnerability of the abundant larval fishes to entrainment. It must be recognized, however, that these estimates are based on temporally and spatially limited sampling efforts which may be representative only of conditions that existed at the time of sampling. These generalizations have little statistical validity because they assume a temporal and spatial uniformity which is unlikely to occur in the study area. They provide pilot assessments of the potential larval proportions entrained by the power plant and potential differences in the relative vulnerability of larval populations to entrainment. For Table 37, relative entrainment vulnerabilities were estimated by using information gathered from the 16-km transect, the proportion of daytime and nighttime larvae in the water column, and the estimated rate of water movements at different depths in the water column. It was assumed that the proportions of larvae captured at each of the transect stations was representative of a lake area between lines 8-km to the north and south of the transect (See Fig. 2). Data from stations P10, P11, and P12 were used to estimate the abundances in the shore zone (arbitrarily defined as within 4-km of shore) and abundances in the three offshore zones centered on the transect were proportioned in relation to known concentrations in the shore zone and the percent captured at stations along the transect. All data from lake stations P10, P11, and P12 and the cooling system were sampled at two to three week intervals; it was assumed that few, if any, larval cohorts were sampled more than once. An estimate of the total abundance of larvae present in the water column during the day was then calculated for an area 16 by 16 km (approximately 10 percent of the shoreline and the area of the western basin). At average wind speeds, all of this area could be within a one-week drift time to the plant intake.

Based on estimates in Table 37, there may be one to two orders of magnitude difference in the vulnerability of different larval species to entrainment. Of course these estimates are crude because of the nature of the sampling effort, but they give some indication of the magnitude of entrainment impact. These estimates would improve by further research, but they indicate that the proportions entrained could be fairly large for certain species, especially freshwater drum and clupeids. Assuming the study area is roughly representative of the whole basin, less than 1 percent of most fish populations were entrained at the plant. However, from 5 to 15 percent of the drum and clupeid larvae may be entrained. Based on theoretical considerations of commercial catch and fecundities, Nelson and Cole (1975) estimated similar percentages for yellow perch. At the present time, the intake at the Monroe Power Plant exceeds the intake of all other cooling waters taken from the western basin in

TABLE 36. ESTIMATED NUMBER OF LARVAE POTENTIALLY ENTRAINED AT THE MONROE POWER PLANT IN 1973*, 1974 and 1975
(millions/year ± mean 95% conf. int.#)

Species	1973	1974	1975
Clupeids	$0 \leq 0.8 \leq 1.6$	$102.1 \leq 168.9 \leq 255.0$	$29.0 \leq 62.9 \leq 102.3$
Carp	$0 \leq 3.3 \leq 6.9$	$94.4 \leq 132.6 \leq 180.3$	$14.8 \leq 25.7 \leq 36.6$
White bass	$1.1 \leq 2.6 \leq 4.1$	$28.1 \leq 95.2 \leq 200.0$	$0.3 \leq 7.8 \leq 15.3$
Yellow Perch	$0 \leq 2.2 \pm 5.1$	$59.6 \leq 83.1 \leq 111.5$	$13.7 \leq 29.3 \leq 44.9$
Channel catfish	$\sim .1$	$6.8 \leq 28.6 \leq 64.9$	$0 \leq 1.7 \leq 4.3$
Freshwater drum	0	$7.8 \leq 20.3 \leq 38.3$	~ 0.1
Shiners	$0.8 \leq 1.6 \leq 2.4$	$1.1 \leq 15.7 \leq 39.6$	$1.4 \leq 10.3 \leq 19.2$
Sunfish	~ 0.3	$1.1 \leq 8.6 \leq 19.9$	$0 \leq 1.4 \leq 3.4$
Bass	0	~ 0.7	~ 0.9
Smelt	~ 0.2	~ 0.7	$0.2 \leq 3.2 \leq 6.2$
Crappie	~ 0.6	~ 0.3	0
Walleye	~ 0.1	~ 0.2	0

(continued)

TABLE 36 (continued).

Species	1973	1974	1975
Suckers	~0.2	~0.2	0
Trout perch	~0.1	~0.2	~0.2
Log perch	~0.1	~0.1	~1.0
Total Larvae	$1.9 \le 12.2 \le 20.1$	$398.4 \le 556.0 \le 841.3$	$59.4 \le 144.5 \le 232.2$

*1973 sampling was completed in mid-June, therefore many species are incompletely represented and numbers are lower than they should be.

#Calculated by multiplying the number of larvae/m^3/sampling date (and associated confidence intervals) at the upper discharge by the volume flow through the cooling system on that date to determine a daily estimate of entrainment. The daily estimate was assumed to represent that sampling date plus half the number of days to a subsequent sampling date. Each daily estimate was multiplied by the number of days that it represented and the sum of these gave the annual estimate of entrainment.

TABLE 37. ESTIMATED RELATIVE VULNERABILITY OF IMPORTANT LARVAL FISH TO ENTRAINMENT AT THE MONROE POWER PLANT FROM AN AREA 16 km by 16 km IN LAKE ERIE IMMEDIATELY ADJACENT TO THE POWER PLANT
(numbers in millions)

			Days to		Estimated Numbers in Relation to Shore‡				Entrainment		Entrainment Percent	
Species	Vel.*	Dist.#	Shore†	Yr.	2 km	6 km	11 km	16 km	Est 1§	Est 2¶	Est 1Ψ	Est 2Φ
Drum	1.0	2.0	2	74	27.50	0.56	0	0	22.47	21.68	80%	77%
				75	0.64	0.01	0	0	49.5	20.56	76%	31%
Clupeids	1.0	7.9	8	73	60.16	51.04	32.81	38.28	37.45	3.30	21%	2%
				74	498.34	422.83	271.82	312.12	688.39	122.67	46%	8%
				75	113.81	218.56	62.08	72.42	141.87	55.67	41%	16%
Shiners	0.9	11.0	12	74	69.44	52.08	86.80	138.88	85.89	17.99	25%	5%
				75	9.05	6.79	11.32	18.11	10.72	9.56	24%	21%
White bass	0.7	13.7	15	74	114.24	371.28	314.16	205.63	119.97	104.04	4%	4%
				75	9.06	29.46	24.93	163.20	7.08	6.88	3%	3%
Smelt	0.9	13.4	15	73	133.12	665.60	272.89	3128.32	85.27	1.18	1%	0.1%
				74	1.47	73.60	301.76	345.92	20.37	0	3%	0
				75	3.93	19.68	80.68	92.49	3.24	2.77	2%	1%
Yellow Perch	0.9	13.9	16	73	19.52	683.20	224.48	653.92	14.90	9.25	2%	1%
				74	75.84	265.44	872.16	2540.64	58.58	83.89	2%	2%
				75	113.92	398.92	1310.08	3816.32	54.90	36.60	1%	0.1%

*This is the average velocity (km/day) that a species population moves. It is calculated from the proportion of fish captured during the day and night from each of the three depths sampled

(continued)

over all dates that larvae were captured. Daytime was assumed to be 14 hrs and nighttime was assumed to be 10 hrs. Each stratum represented a proportion of the total population present. The proportion captured was multiplied by the estimated water velocity for that stratum and the results summed over all strata. Mean surface and midwater current velocities were assumed to represent 2% of the mean resultant wind velocity while the deep current represented 10% of the surface current (Hutchinson, 1957):

$$\sum_{i=1}^{n}\left[\frac{\sum_{i=1}^{x}\overline{D}_i P_D + \overline{N}_i P_N}{\sum_{i=1}^{n}\left(\sum_{i=1}^{x}\overline{D}_i P_D + \overline{N}_i P_N\right)} \cdot V_D\right] = V_H$$

Where $\overline{D}_i$ = mean number/m^3 captured during the day for each depth stratum; where N_i = mean number/m^3 captured during the night for each depth strata; where P_D = proportion of daylight hrs; P_N = proportion of the nighttime hours; n = number of strata; x = number of dates with fish in samples; V_D is the mean horizontal water velocity; V_H = mean horizontal velocity of population.

#The mean capture distance from shore was calculated by apportioning the total number of larvae for each species captured along the transect into the propotion of the total each transect station represented. The proportion captured at each station was then multiplied by the distance from shore and the results were summed:

$$\sum_{i=1}^{n}\left(\frac{t_i D_i}{T}\right) = \overline{D}$$

Where T = total number/m^3 caught at all 4 stations along the transect; where t_i = number/m^3 caught at each station along transect over all sampling dates; where D_i = distance of each transect station from shore; where $\overline{D}$ = mean capture distance from shore.

(continued)

† The average number of days to move larvae to the intake at the power plant was calculated by dividing the mean capture distance from shore by the weighted horizontal velocity:

$$\frac{\overline{D}}{V_H} = \text{Days}$$

‡ The estimated numbers present at different distances from shore was calculated by assuming the mean catch at the three lake stations (or one in 1973) within 2 km of shore represented the total capture within the first 2 km plus half the distance to the second transect station during the time larvae were estimated to be present. The volume within an area 16 x 4 km was calculated with a mean depth of 5 m, and the number of larvae within that volume was determined. Using the prior proportion of larvae captured along the transect in 1975, the total present within a 16 x 16 km area was determined and the number within each transect sector was determined:

$$A_1 = \overline{F} \cdot V_1$$

$$A_2 = \overline{F} \cdot V_2 \cdot t_2/T$$

$$A_3 = \overline{F} \cdot V_3 \cdot t_3/T$$

$$A_4 = \overline{F} \cdot V_4 \cdot t_4/T$$

Where $\overline{F}$ = mean catch/m^3 at station P10, P11, and P12 (or station P5 in 1973) over all dates of capture. Where V = volume of area surrounding P10, P11, and P12 (16 x 4 km) to a depth of 5 m. Where A_1 = area in first transect sector (Figure 1); where A_2 = area in second sector; where A_3 = area in third transect sector; where T = total number/m^3 caught at all 4 stations along the transect; where t_2 = number/m^3 caught at station P14; where t_3 = number/m^3 caught at station P15; where t_4 = number/m^3 caught at station P16.

(continued)

[§] Theoretical maximum lake entrainment was estimated by assuming maximum pumping of cooling water ($85 m^3/sec$). By weighting the amount of water derived from the lake compared to the amount from the river for each month the larvae were present, a mean daily lake water requirement was computed. The weighted mean lake water requirements per day was extrapolated to the length of time a particular larval species would be present to yield the total lake water requirements. This water was assumed to be obtained primarily from the immediate 4 km area while any additional requirements would be met by the succeeding areas. The percent of the water derived from each transect sector was calculated and that percent also represented the percentage number of larvae entrained. This percent was multiplied times the number present in the transect sector to yield numbers entrained. G = larvae in first transect sector plus any additional larvae from adjacent sector, if required; V = volume within first sector of transect and additional volume from adjacent sector, if required; L = length of time (captured days + 14) larvae estimated to be present; R_i = riverine larvae entrained over period that larvae were present:

$$E = \frac{G\ V}{\sum_{i=1}^{n} \left(1 - \frac{R_i}{C} \right) (C)(L)}$$

[¶] The theoretical maximum condenser passage assumed an $85\ m^3/sec$ pumping rate. The mean number/m^3 of larvae captured in the upper discharge canal was multiplied by the total number of days the larvae were estimated to be present. This number was then multiplied by the total amount of water pumped during a comparable time period yielding the total number of larvae present.

C = as above
$\overline{U}$ = mean number of larvae/m^3 captured in upper discharge canal
L = length of time larvae estimated to be present (days of capture = 14 days)
M = estimated number of larvae to pass through condenser
$M = L\ [(\overline{U})(C)]$

[Ψ] Percent total entrainment was calculated by comparing the theoretical maximum entrainment to the total number of larvae estimated to be present within a 16 x 16 km area.

[Φ] Percent total condenser passage was calculated by dividing the estimated lake population by the maximum number estimated to pass through the condenser.

Lake Erie, by about 2 to 1. However, future expansion on the Great Lakes may require 10 times the present cooling needs over the next few decades. Therefore, the potential mortality percentages of drum and clupeids border on those that may have a measurable impact on adult populations, especially in the distant future.

Jensen (1971) has indicated that a reduction of as little as 5 percent in recruitment may eventually affect the adult population of at least one species of fish. Beland (1974) has questioned Jensen's conclusions and there have been no empirical studies published that verify these kinds of projections. Determining a 5 percent impact on recruitment with statistical confidence for any particular year of study would demand a much more intensive sampling effort than that executed during this study because of the high variability in larval fish distributions.

The variability is derived from vertical and horizontal variation, and temporal variation caused by changing rates of larval recruitment. Although variability at a particular sampling site in the lake may be only moderately high, the variability among different stations only a few kilometers apart often is high and inconsistent from one day to the next. This "patchiness" greatly affects any assessments of change in population abundance within the cooling system as well as estimates of the proportions of lake populations that are entrained. We do not know enough about the lengths of time that larvae are susceptible to net capture and the probability of overestimating or underestimating the actual number of larvae recruited into the lake population. At the intensity of sampling applied during these studies, the annual entrainment of abundant populations may be reasonably estimated, at a 95 percent confidence interval, within 100 to 1000 percent of the mean. Variability in the lake is as great as variability in the cooling system. Consequently, the intensity of sampling in the lake must be comparable to that in the cooling system to produce similar confidences.

Taking into consideration the exploratory nature of these pilot studies, there is a need to refine estimates. Future estimates of larval fish distribution and potential entrainment could be improved in several ways. Almost all of the fish are most vulnerable to entrainment at night because they are in the faster moving waters near the surface. Therefore, horizontal distributions would be better estimated at night anywhere night navigation is feasible. If night sampling proves infeasible, a combination of sled-netting and oblique tows should be used during the day. If this combination is not used, the densities of larvae are likely to be underestimated in deeper water. The actual growth rate of larval fish and their capacity to avoid net capture as they grow should be better evaluated. Also, the relative vulnerability of larval fish to natural mortality should be identified as it is related to distribution. Are near-shore populations more likely to die from natural causes than off-shore populations? Are larvae that hatch in the tributaries more likely to survive to reproductive age classes than those that hatch in the lake? Answers to these questions should provide suitable information for the appropriate siting and operating of cooling systems and other coastal zone management.

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